

Stock assessment for Seto Inland Sea stock of Bastard halibut (*Paralichthys olivaceus*) in Fiscal Year 2022

Fisheries Stock Assessment Center, Fisheries Resources Institute, Japan Fisheries Research and Education Agency

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Summary

The biomass of this stock was calculated using cohort analysis with tuning, and the Small trawl fishery CPUE (catch per unit effort) was used as the index of abundance. The catch remained around 1,000 tons from 1988 to 2002, and then declined to 482 tons in 2016. After 2017, the volume began to increase and reached 615 tons in 2020, but declined slightly to 576 tons (approximate value) in 2021. Biomass reached 2,900 tons in 1998, and then declined to 1,800 tons in 2015, and increased to 3,800 tons in 2021. SSB (spawning stock biomass) reached 1,600 tons in 2000, and then slightly decreased and remained stable. Since 2016 it has been in an increasing trend, and was estimated to be 2,800 tons in 2021.

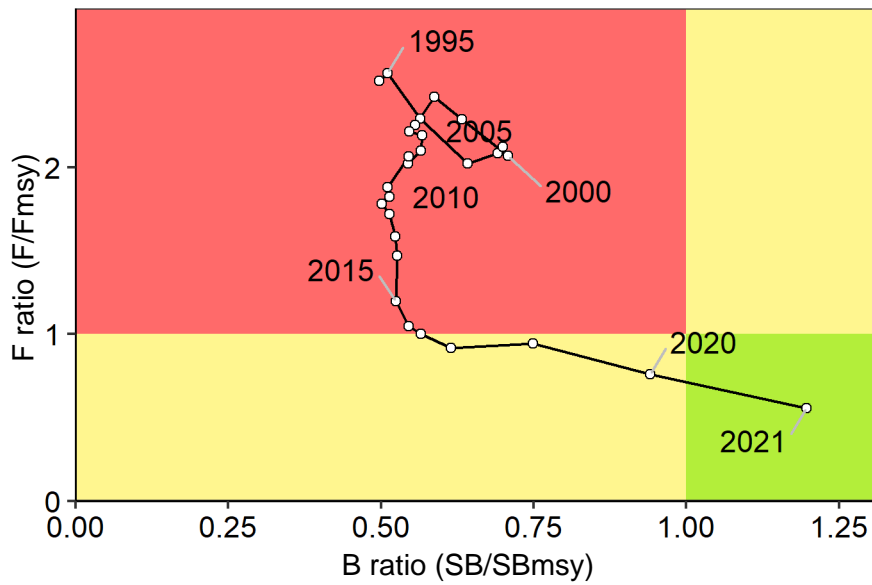
This species is a target species of stock enhancement, and 2.45 million hatchery-reared fish were released in 2020. The contribution rate of hatchery-released fish in the 2020 age 0 catch was estimated to be 53%, and the survival to recruitment of released fish (the survival rate of released fish to fishery recruitment) was very high at 0.34. This was due to the very high frequency of hatchery-released fish in the sample of age 0 fish from the eastern Seto Inland Sea, while the previous 2017 to 2019 average contribution rate was 11% and survival to recruitment of released fish was 0.08. Recruitment (age 0 stock abundance) for this stock ranged between 870,000 to 4,250,000. Within this total, the recruitment of wild fish exceeded 2,500,000 in 1994, 1995, and 1997, and thereafter generally remained in the range of 700,000 to 2,000,000. Fishing pressure has been in a decreasing trend since the late 2000s, and furthermore, fishing pressure for age 0 and age 1 has remained at low values since

around 2015. It is inferred that low fishing pressure and relatively stable recruitment in this stock have led to a steady increase in biomass in recent years.

In the Research Institute Meeting held in September 2021, a Hockey stick model was applied to the stock-recruitment relationship of this stock, and based on this, the maximum sustainable yield (MSY) was estimated, and the level of SSB required for MSY (SB_{msy}) was calculated to be 2,400 tons. Following these criteria, SSB of this stock in 2021 exceeds the level required for MSY. The fishing pressure for this stock in the 2021 was lower than the fishing pressure level required for MSY (F_{msy}). Based on trends seen in the previous 5 years (2017 to 2021), SSB is judged to be in an “increasing” trend.

In this stock, the reference points, future projections, and other items are provisional values as proposed at the Research Institute Meeting, which will be finalized based on discussions of the stakeholder meeting.

Summary Figures and Tables



MSY, Levels and Trends in SSB, and ABC	
SSB required for MSY	2,400 tons
Level of SSB in 2021	Over the level required for MSY
Level of fishing pressure in 2021	Under the level required for MSY
Changes in SSB in 2021	Increase
Maximum Sustainable Yield (MSY)	806 tons
ABC for 2023	-
Comments: <ul style="list-style-type: none"> • ABC is estimated after Harvest Control Rules (HCRs) for this stock are compiled by the stakeholder meeting, and set through the Fishery Policy Council. • Recent fishing pressure has been low, and biomass has shown a gradual upward trend. 	

Recent Biomass, Catch, Fishing Pressure, and Exploitation Rate					
Year	Biomass (hundred tons)	SSB (hundred tons)	Catch (tons)	F/Fmsy	Exploitation rate (%)
2017	20	13	504	0.99	26
2018	23	14	519	0.91	23
2019	28	17	588	0.94	21
2020	33	22	615	0.76	18
2021	38	28	576	0.55	15
2022	43	34	654	0.55	15
2023	46	37	-	-	-

- Catch for 2021 is approximate value.
- The values for 2022 and 2023 are estimates based on future projections.

1. Data Sets

The data sets used for this stock assessment are as follows:

Data Sets	Basic Information & Related Surveys
Catch in number at age and by year Data on the collection of hatchery-reared fish released into the wild	Fishery Trends in the Seto Inland Sea and Southern Pacific Ocean Areas (Chugoku-Shikoku Regional Agricultural Administration Office, up to 2005) Annual Statistics of Fishery and Aquaculture Production (Fisheries Agency, 11 prefectures from Wakayama to Oita) Biological Information Survey (Osaka, Hyogo, Hiroshima, Yamaguchi, Oita, Ehime, and Kagawa) <ul style="list-style-type: none"> • Total length composition measurement • Precision measurement (total length, body weight, age assessment, detection of individuals with hypermelanosis on blind side)
Recruitment volume index	Preliminary recruitment survey in coast of Habu, Yamaguchi Prefecture (Japan Fisheries Research and Education Agency)
Natural mortality (M)	Assuming $M = 0.31$ per year (estimated by the method of Tauchi and Tanaka (Tanaka 1960))
Fishing effort	Fishery Trends in the Seto Inland Sea and Southern Pacific Ocean Areas (Chugoku-Shikoku Regional Agricultural Administration Office, up to 2005) Annual Statistics of Fishery and Aquaculture Production (Fisheries Agency, 11 prefectures from Wakayama to Oita) Sample vessel survey (Yamaguchi, Oita) Survey on Catch Status by Fishing Ground (data on catch and effort in Small trawl fisheries was collected from sample fisheries cooperatives in 11 prefectures from Wakayama to Oita)*
Number of hatchery-released fish, tag rate (percentage of hypermelanic individuals at the time of release), etc	Results of production, procurement, and release of seeds for stock enhancement (Resources Enhancement Promotion Department, Fisheries Agency; Japan Fisheries Research and Education Agency; and National Association for Promotion of Productive Seas (NAPPS)) Data on hypermelanosis rate at the time of release (2021 results: Wakayama, Osaka, Hyogo, Hiroshima, Yamaguchi, Kagawa, and Ehime Prefectures)

*The CPUE obtained from the Small trawl fishery catch in weight and effort of the sample fisheries cooperatives in this research was adopted as the index of abundance for the tuning cohort analysis.

2. Ecology

(1) Distribution / Migration

This stock is distributed mainly along the coast of the Seto Inland Sea (Figure 2-1). Larva and juvenile fish born in the Seto Inland Sea in the spring grow up in an area immediately adjacent to the coast and then gradually migrate to its offshore areas. After reaching maturity, some remain in the Seto Inland Sea, while others migrate out to the open sea. Those that migrate out go to the Kii Strait in eastern waters (Kii Strait, Osaka Bay, Harima-nada, Bisan-Seto) and to the Bungo Channel in central (Hiuchi-nada, Bingo-Geiyo Seto, Aki-nada) and western waters (Iyo-nada, Suo-nada) (Ehime Prefecture 1995, Tokushima Prefecture 1995, Yamaguchi Prefecture 1995).

(2) Age / Growth

There is a marked difference in growth between the sexes in this species. Females grow larger than males, with females weighing more than twice as much as males at age 5. The lifespan is unknown, but the oldest precision-measured individual from 1994 to 2021 was 16 years old.

Using total length, body weight, and age of individuals based on precision measurements from 1995 to 2004, the von Bertalanffy growth equation with age t and total length L_t (cm), and allometric equations with total length L (cm) and body weight W (g) were estimated for each sex (Fig. 2-2). Here, ages were determined using otolith thin sections.

$$\text{Age-Total Length Equation Male: } L_t = 62.78 (1 - \exp(-0.29(t + 0.96))) \quad (1)$$

$$\text{Female: } L_t = 92.94 (1 - \exp(-0.24(t + 0.59))) \quad (2)$$

$$\text{Total Length-Weight Equation Male: } W = 0.0072 L^{3.10} \quad (3)$$

$$\text{Female: } W = 0.0047 L^{3.23} \quad (4)$$

In this age-length equation, t sets the start date for age calculation to April 1, which differs from the start date for age calculation: January 1 in the cohort analysis shown in “4. Stock Status”.

(3) Maturation / Spawning

The eastern spawning grounds are thought to be waters in the Pacific side of Tokushima Prefecture, and the central and western spawning grounds are thought to be waters in Suo-nada, Iyo-nada, Itsukinada (Ehime Prefecture), west of Hiuchi-nada, and the islands (Fig. 2-1) (Ehime Prefecture 1995, Tokushima Prefecture 1995, Yamaguchi Prefecture 1995). Spawning season is from February to May in the eastern waters, and from March to June in the central and western waters. Maturity rate at age (Fig. 2-3) is 4% for females at age 1, 75% at age 2, 82% at age 3, and 100% at age 4 and older; for males, 4% at age 1, 52% at age 2, 91% at age 3, and 100% at age 4 and older (Ehime Prefecture 1995, Yamaguchi Prefecture 1995).

(4) Predator-Prey Relationships

Juveniles that settled on the bottom of the coastal nursery grounds feed primarily on mysids, and the proportion of predation on crangonid shrimp and fish increases with growth. After recruitment, individuals feed primarily on fish, and also on crustaceans and squids (Ehime Prefecture 1995, Tokushima Prefecture 1995, Yamaguchi Prefecture 1995). Regarding predation, there have been reports of hatchery-reared juveniles being preyed upon by large fish such as bastard halibut, flathead, and Japanese seabass after the release (Ehime 1995, Hiroshima 1995, Yamaguchi 1995), but data is not available for wild fish.

3. Fishery Status

(1) Fishery Overview

This species is mainly caught by Small trawl fishery, Gill net fishery, Set net fishery, and Anglings (including Long line fishery). The catch by fishing method was mainly Small trawl fishery at 55%, with Gill net fishery at 25%, Set net fishery at 15%, and Anglings at 5% in 2021 (Fig. 3-1). The catch is dominated by immature fish in the fall and mature fish in the winter to spring.

The Small trawl fishery of the Suo-nada, the “Memorandum on Stock Management for Target Species of Suo-nada Small Trawl Fishery” has prohibited the catch of bastard halibut less than 25 cm in total length since 2004. In addition, some prefectural fisheries cooperatives have also established similar landing size limits (mostly 25 cm in length) and closed fishing days. In some waters, because small fish less than 25 to 30 cm in length have a low unit price, there are cases where small fish sorted on board are not landed and are re-released instead (information from the relevant prefectural Fisheries Experimental Stations).

(2) Trends in Catch

Catch was around 100 to 500 tons until the early 1970s, but increased from the late 1970s through the 1980s, reaching 1,042 tons in 1989 (Fig. 3-1, Table 3-1). From 1988 to 2002, catch remained around 1,000 tons, but dropped below 1,000 tons in 2003 and onwards, and fell to 482 tons in 2016. After that, it was in an increasing trend, and reached 615 tons in 2020, followed by a slight decline to 576 tons (approximate value) in 2021.

Figure 3-2 shows trends in annual catch in number at age by year from 1994 to the present, and Figure 3-3 shows trends in catch in weight at age. In terms of catch in number, after reaching a high of 2.73 million in 1995, catch in number was in a decreasing trend until 2016, then increased from 2017 to 2019, while the total catch in number in 2020 and 2021 also decreased slightly due to a decrease in the catch in number of age 1 fish (Fig. 3-2). The age 1 and age 2 catch accounted for 60 to 80% of the total catch, and when age 0 fish are included, individuals age 2 and younger accounted for more than 90% of the total catch in many years before 2005, but the catch of young fish, especially age 0 and age 1, has declined since then. In terms of weight, the peak in 1999 was followed by a decreasing trend until 2016, which was similar to trends in catch in number, but the average individual body weight increased due to a shift in the catch target age group from younger to older fish, and the rate of decline was more gentle than that of catch in number (Fig. 3-3).

The amount of fish caught by recreational fishing was very small at 2 tons in 1992, and 7 tons in 1997 and 2001 (Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries 1993, 1998, 2003), but in 2008 it reached 81 tons, accounting for 9.7% of the total catch in weight (Fisheries Coordination Division, Resources Management Department, Fisheries Agency, Data from the fiscal year 2008 Recreational Fishing Catch Survey Report <https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00502002&tstat=000001031445&cycle=8&year=20081&month=0&tclass1=000001031446&tclass2=000001031447>, accessed: July 31, 2018). Since then, no data on recreational fishing catches by area has been published.

(3) Fishing Effort

Effort (total number of fishing days) for Small trawl fishery and Gill net fishery from 1968 to 2006 decreased since 1979 for Small trawl fishery and since 1983 for Gill net fishery (Fig. 3-4, Table 3-2). Effort (number of fishing units) for small set net fishery remained flat between 2,000 and 2,200 units from the late 1970s to the early 1990s, but then declined. Since 2007, the Annual Statistics of Fishery and Aquaculture Production no longer aggregates effort using this format.

Since 2002, data on monthly catches of bastard halibut and the total number of vessels*days at sea have been collected from Small trawl fishery sample vessels (Oita and Yamaguchi Prefectures) and Small trawl fishery sample fisheries cooperatives (Izumisano, Goshiki-cho, Takasago, Hinase, Aji, Tosan, Uchinomi, Kawarazu, Kaminada, and Iyo) along the Seto Inland Sea coast (Fig. 3-5, Table 3-3). Note that for some fisheries cooperatives, effort has been tracked since 2000, but the corresponding catches have only been tracked since 2002. Annual totals of the total number of vessels*days at sea for these sample vessels and sample fisheries cooperatives have been declining every year since 2004, when the sample fisheries cooperatives currently tracking information became available. The total number of vessels*days at sea in 2004 was 45,000 vessels*days, while in 2021 it was 17,000 vessels*days, which is about 40% of 2004.

4. Stock Status

(1) Stock Assessment Methods

Using age-assessed data on individuals caught and precisely measured since 1994, Age-Length keys for age 0 to 5+ were created and updated by adding the new data registered each year, for each sex in the three seasons of January-April, May-August, and September-December (Supplementary Table 2-1). After obtaining the catch in number by sex by age group by year, taking into account the composition and sex ratio by length class, mean weight by length class by sex, and monthly (or seasonal) catch, a tuned cohort analysis was conducted using CPUE for Small trawl fishery of sample vessels and sample fisheries cooperatives as an indicator of relative abundance to estimate the stock population at age by year, biomass, and SSB (Appendix 1 and 2).

(2) Trends in Abundance Indices

Trends in CPUE for Small trawl fishery, Gill net fishery, and small set net fishery from 1970 to 2006, based on the Annual Report of Fishery and Aquaculture Production Statistics, are shown in Fig. 4-1 and Table 3-2 (CPUE, kg/number of days at sea for Small trawl fishery and Gill net fishery, tons/fishing unit for small set net fishery). For all fishing methods, there was an increasing trend from the 1980s to the 1990s, followed by a flat trend after 2000. Subsequently, the number increased again in 2005 and 2006 for small set net fishery and in 2006 for Gill net fishery. In 2006, the CPUE for Small trawl fishery, Gill net fishery and small set net fishery was 0.77, 0.41, and 0.07, respectively, which increased to 8.6, 8.2, and 7.0 times the CPUE in 1970 (0.09, 0.05, and 0.01, respectively).

The weighted average for Small trawl fishery CPUE (kg/vessel/day) since 2002 collected from sample vessels and sample fisheries cooperatives is shown in Fig. 4-2 and Table 4-1. Looking at the trends here, CPUE was in a declining trend since 2005 and then remained around 0.7, although it fluctuated from year to year, then it increased sharply to 1.29 in 2019, and further increased to 1.94 in 2020. The value in 2021 was 1.91, which was about the same as in 2020.

(3) Trends in Biomass and Fishing Pressure

The stock abundance (Fig. 4-3) peaked at 8.05 million in 1995, and biomass (Fig. 4-4) peaked at 2,900 tons in 1998 before gradually declining to 2.62 million fish and 1,800 tons in 2015. Both in

terms of abundance and biomass, the stock increased since 2016, and in 2021 the stock abundance was 4.91 million and biomass was 3,800 tons. SSB reached 1,600 tons in 2000, and then decreased and remained around 1,200 to 1,300 tons after 2003, then has been increasing since 2016 (Fig. 4-5). SSB in 2021 was estimated to be 2,800 tons, which replaced 2020 as the new record high since 1994. Recruitment (age 0 stock abundance) peaked at 4.25 million fish in 1995 and then was in a decreasing trend, reaching 0.87 million in 2015 (Fig. 4-5). The abundance then increased to 2.03 million in 2019 before decreasing slightly to 1.31 million in 2021.

A sensitivity analysis of biomass, SSB, and stock abundance at age 0 when the natural mortality (M) value is fluctuated ± 0.1 (68 to 132%) resulted in a change of 80-130% for biomass, 81-129% for SSB and 77-136% for stock abundance at age 0 (Fig. 4-6 to 4-8).

Trends in F by age show that since the 2000s, F has been in a decreasing trend for all age groups age 0 to 3, except for age 4 and older, and since around 2010, age 4 has also been in a decreasing trend (Fig. 4-9). Comparison of F for each age group shows that the F at age 2 was generally the highest until about 2010, then it remained around the same level as the F at age 3, and since around 2015, the F at age 4 and age 5 and older have also remained at the same level. Prior to 2009, the F at age 1 exceeded the F of the oldest groups, which are age 4 and age 5 and older, but afterwards the F at age 1 was generally been lower than the F at age 4 and age 5 and older, and the remained below 0.2 since 2016. F at age 0 has similarly been low in recent years and has remained below 0.04 since 2015. These facts suggest that fishing pressure itself has been decreasing since the 2000s, and that the main target age group for catches has shifted from younger fish to older fish. Similar to F, the exploitation rate has also been in a decreasing trend since the 2000s, and remained around 40% until around 2010, and then decreased to 15% in 2021 (Fig. 4-10).

Compared to the stock assessment of the previous fiscal year, no significant differences in biomass and SSB estimates were found. However, recruitment in number in 2019 was retroactively revised upward due to the relatively large catch of age 2 fish (the 2019 cohort) in 2021.

(4) Stock enhancement and recruitment

This species is a typical target species of artificial stocking, and stock enhancement have been implemented in the Seto Inland Sea since the late 1970s. The number of released fish remained at around 4 to 5 million per year from the late 1990s to 2008, but has been in a decreasing trend since then, with 2.45 million released in 2020 (Fig. 4-11).

The recruitment in this stock was estimated by separating the age 0 stock abundance obtained using cohort analysis into recruitment of wild fish and recruitment of hatchery-reared fish (see Appendix 2 (3)). The results of the hypermelanic individual contribution rate in the age 0 catch in number based on the Biological Information Surveys (precision measurement) conducted by each Fisheries Experimental Station, corrected with the hypermelanosis rate at the time of release, showed that the (corrected) contribution rate of hatchery-reared fish to the age 0 stock population from 1995 to 2020 ranged between 7 and 53% (Table 4-3). However, in 2020, the contribution rate was estimated to be 53% and the survival to recruitment of released fish (the survival rate of released fish to fishery recruitment) was estimated to be 0.34, which are very high levels, but this is because the frequency of

hatchery-released fish was very high only in the sample of age 0 fish in the eastern Seto Inland Sea, and therefore, it is highly possible that the results do not reflect the situation in the Seto Inland Sea as a whole. Furthermore, the most recent average contribution rate (2017 to 2019) was 12% and survival to recruitment was 0.08. Therefore, for the recruitment of hatchery-reared fish in 2021, when the number of released fish was not determined, the 2020 value was removed due to high uncertainty, and it was estimated as the average survival to recruitment multiplied by the average number of released fish from 2017 to 2019.

Recruitment of hatchery-reared fish ranged from 0.7 million to 1.3 million, with a record high in 1998 and a record low in 2015 (Table 4-2, Fig. 4-5). The recruitment of wild fish exceeded 2.5 million in 1994, 1995, and 1997, but then ranged between 0.72 million (2020) and 1.99 million (2003), with the exception of 2.35 million in 2001. The age 0 stock population of the 2018 cohort, which was inferred to be a strong cohort in the initial assessment, was estimated to be 1.79 million in this year's assessment, and the age 0 stock population of the 2019 cohort was estimated to be 1.89 million. These are considered to have been relatively good recruitment periods, second only to the 2003 cohort.

(5) Yield Per Recruit (YPR), Spawning Per Recruit (SPR), and Current Fishing Pressure

In order to compare fishing pressures with consideration for selectivity, we compared findings for spawning per recruit (SPR) in scenarios with and without fishing pressure. Fig. 4-12 shows changes in the SPR ratio (%SPR), which compares SPR in a scenario without fishing pressure against SPR in a scenario with fishing for each year. Lower fishing pressure means higher %SPR levels. %SPR follows an increasing trend, reaching 45% in 2021.

The relationship between current fishing pressure and YPR and %SPR is shown in Fig. 4-13. The current fishing pressure (F2022), the value used to estimate the F (F_{msy}) needed to achieve maximum sustainable yield (MSY) at the Research Institute Meeting held in September 2021 (Yamashita et al. 2021) was used for selectivity, and the 2021 value (45%) was used for %SPR. In addition, the values used to calculate F_{msy} were also used for average body weight at age and the maturity rate. F_{msy} is equivalent to 28% when converted to %SPR. The current fishing pressure (F2022) is below F_{msy}, F0.1, and F30%SPR.

(6) Stock-Recruitment Relationship

The relationship between SSB in weight and recruitment abundance (stock-recruitment relationship) is shown in Figure 4-14. The Research Institute Meeting mentioned earlier has applied the Hockey-stick model to the stock-recruitment relationship model for this stock (Yamashita et al. 2021). The data used to estimate the parameters of the stock-recruitment relationship are SSB and recruitment from 1994 to 2019 based on the stock assessment for the Fiscal Year (FY) 2021 (Yamashita et al. 2022). Only recruitment of wild fish was used for recruitment. The optimization method used was the least squares method, and autocorrelation of the residuals in recruitment was taken into account. In accordance with the Guidelines for Determining the Stock-Recruitment Relationship (FY2021) (FRA-SA2021-ABCWG01-03), the inflection point was set as the minimum SSB level in the observation range. The parameters of the stock-recruitment relationship model are shown in

Supplementary Table 6-1.

(6) Levels Required for MSY Under Current Environmental Conditions

The SSB required for Maximum Sustainable Yield (SBmsy) and the catch in weight required for MSY, under current environmental conditions (1994 and onward), were defined as the values estimated at the aforementioned Research Institute Meeting (Yamashita et al. 2021), and are shown in Supplementary Table 6-2.

(8) Stock Levels/Trends and Fishing Pressure Levels

Reference values for SSB and fishing pressure required for MSY are shown in a Kobe plot in Fig. 4-15. In addition, a summary of SSB and fishing pressure in 2021 is shown in Supplementary Table 6-3. SSB of this stock in the 2021 was higher than the SSB required for MSY (SBmsy), specifically, SSB in the 2021 fishing season was 1.14 times the value of SBmsy. In addition, the fishing pressure in 2021 was lower than the fishing pressure required for MSY (Fmsy), specifically, it was 0.55 times the value of Fmsy. The F ratios (F/Fmsy) shown in the Kobe plot are the ratio between F values in each year, and the value of F that gives the fishing pressure of Fmsy converted by %SPR under the selectivity of F in each year. The trend in SSB was determined to be an increase based on the trend over the recent 5 years (2017 to 2021). The SSB of this stock remained below SBmsy up to 2020, but fishing pressure has decreased below Fmsy since 2017, and SSB in 2021 increased to levels above SBmsy.

5. Summary of Stock Assessment

The SSB in 2021 was above SBmsy and increased relative to 2020, itself the highest year since 1994. VPA analysis indicates that the fishing pressure of this stock has been in a long-term decreasing trend. Although there is a high degree of uncertainty in the age 0 stock population in recent years, fishing pressure on juveniles in particular appears to be at a low level. Since 2018, fishing pressure has decreased below the fishing pressure level required for MSY (Fmsy), and it is inferred that low levels of fishing pressure and stable recruitment in this stock have led to a steady increase in biomass in recent years.

6. Additional Comments

Reducing F for small and immature fish (age 0 and age 1), is effective in avoiding overfishing of both mature fish and recent recruits. Currently, some regions and fishing cooperatives have implemented catch size restrictions, and in other regions, there appears to be a voluntary reduction in the catch of small fish due to the low price. It is highly likely that these measures contributed to the reduction of F in small fish. Even if large-scale catch control measures that would drastically reduce the fishing pressure of all bastard halibut fisheries cannot be implemented, as effort and F are already tending to decrease year by year (Fig. 3-5 and 4-9), technical controls such as the introduction of catch size regulations for small fish in all areas, or standardizing the various catch size regulations in different areas to the standards of more major regions, are expected to have the effect of enabling the

stock to be exploited in a healthier manner for a longer period.

As for the early identification of recruitment, a survey of wild juvenile bastard halibut was conducted every June from 1995 to 2020 in Hiuchi-nada, which is considered to be the peak settlement season, but the survey was discontinued because it no longer aligned with recruitment trends in subsequent stocks. An alternative survey to identify recruitment is currently under consideration, and a preliminary survey of age 0 bastard halibut has been conducted along the Habu coast of Yamaguchi Prefecture since 2021.

The stock enhancement program of bastard halibut have been actively conducted in each prefecture along the Seto Inland Sea coast (Table 4-3), and hatchery-reared stock accounts for 10 to 50% of the age 0 stock abundance depending on the year, so it is considered to supplement the wild stock (Fig. 4-5). However, since information on the tag rate at the time of release, which is the basic data for determining stocking effectiveness, is currently available only from a limited number of prefectures, it has not yet been possible to calculate survival to recruitment in more detailed units of water bodies such as by sea area (nada) or by prefecture. Furthermore, as the production technology of hatchery-reared bastard halibut has improved, it has become possible in recent years to produce some lots with no individuals with hypermelanosis on the blind side. These “high-performing” lots are difficult to detect by conventional methods for determining stocking effectiveness. Accordingly, there are concerns that in the future, it may not be possible to determine the stocking effectiveness of releasing fish at all. Therefore, the hypermelanosis rate of seeds for release should be monitored and ensured by the organizations and institutions responsible for releasing hatchery-reared fish, as well as the organizations and companies that produce the seeds, and this data should be reported through the prefectural governments or Fisheries Resources Institutes to allow the collection and analysis of more accurate information. This data is very important for determining how much the release of hatchery-reared bastard halibut contributes to the maintenance of the stock in each region.

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(Authors: Yuuho Yamashita, Tetsuo Yamada, Akihiro Manabe, Hideo Sakaji)

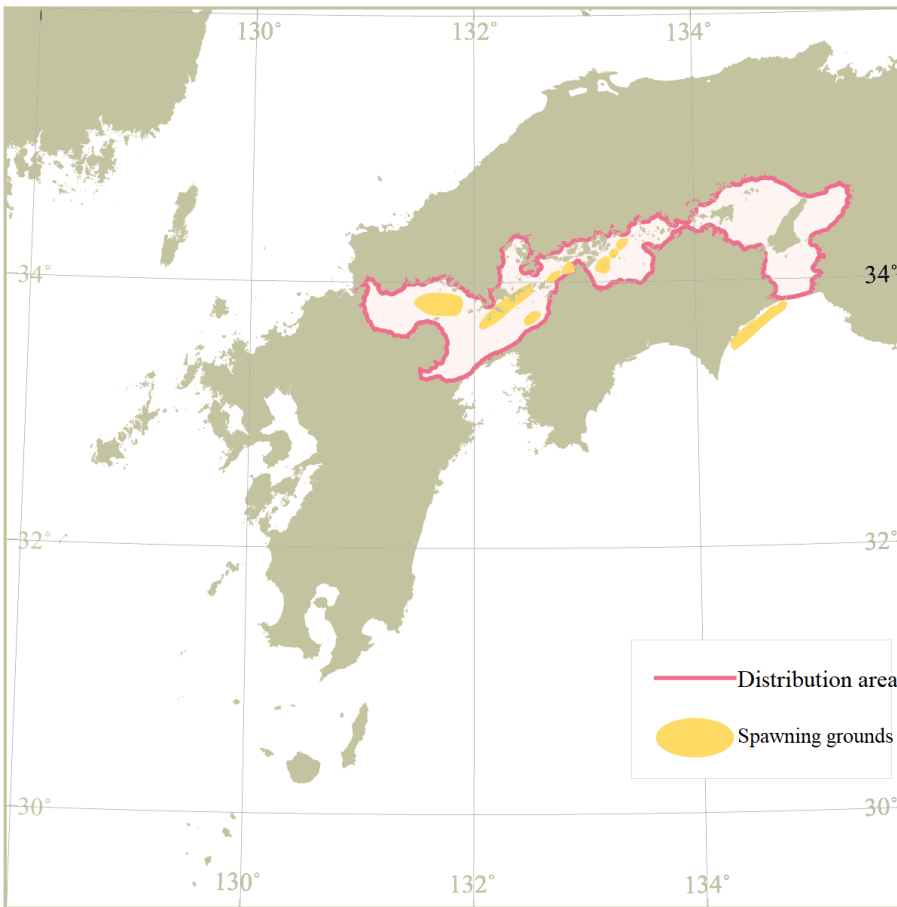


Fig. 2-1. Distribution of Seto Inland Sea stock of bastard halibut

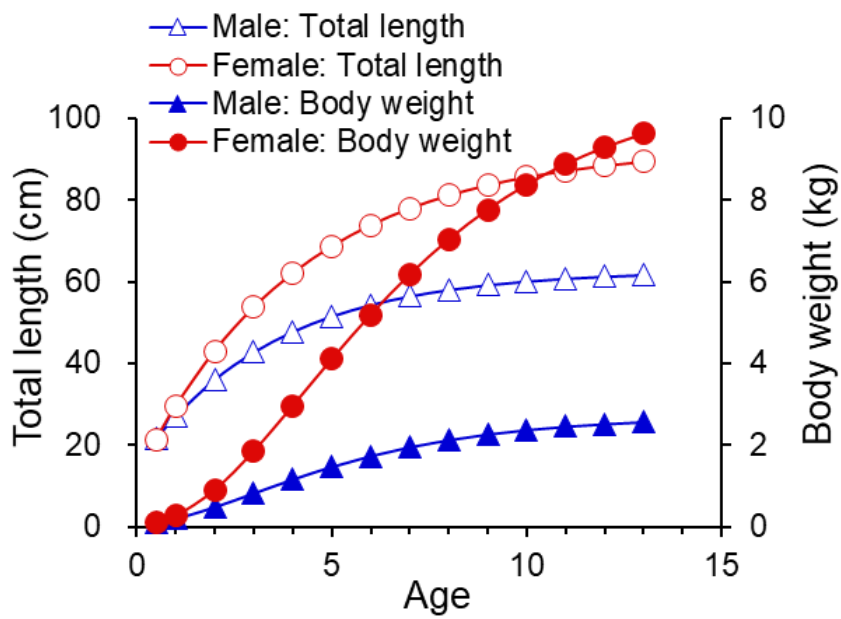


Fig. 2-2. Relationship between age, total length, and body weight by sex (age is calculated from April 1)

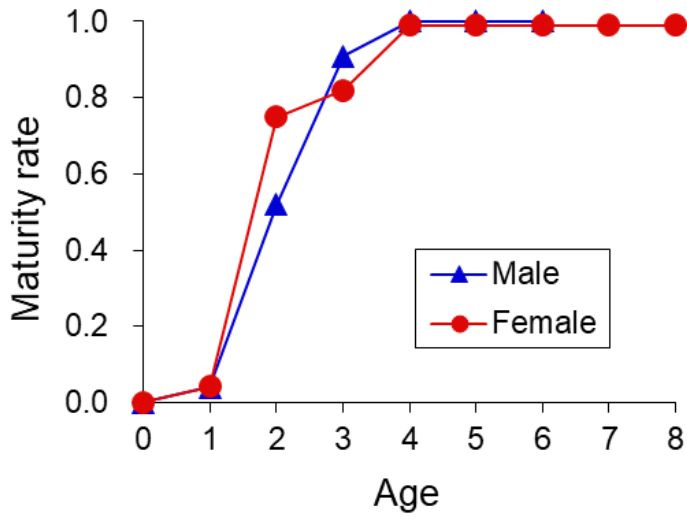


Fig. 2-3. Maturity rate at age by sex

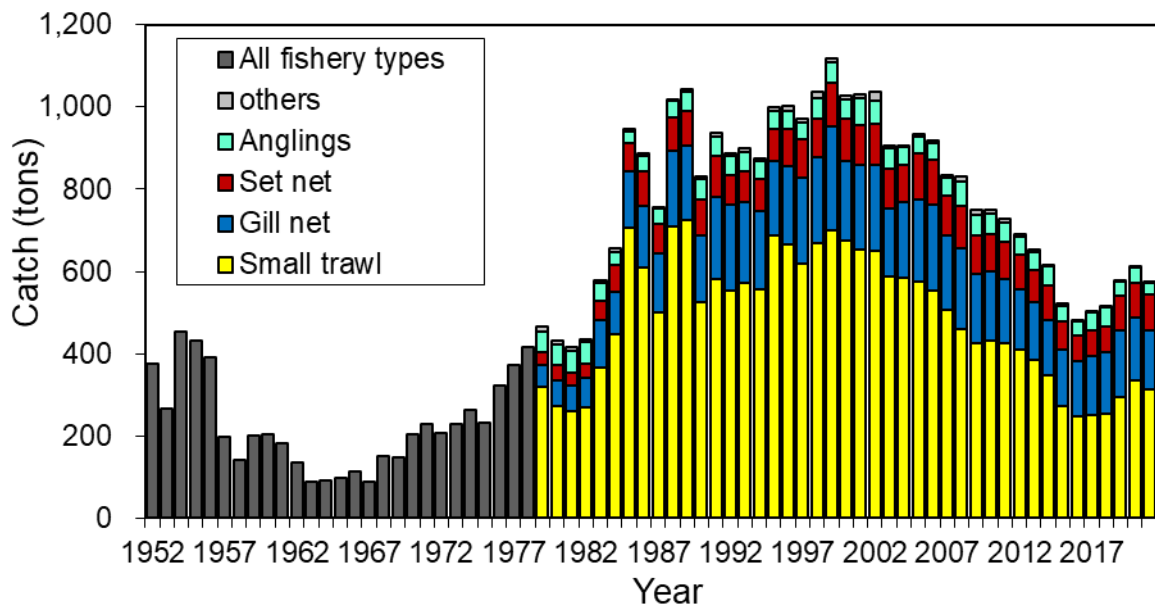


Fig. 3-1. Trends in catch by fishery type. Prior to 1978, figures are totals for all fisheries.

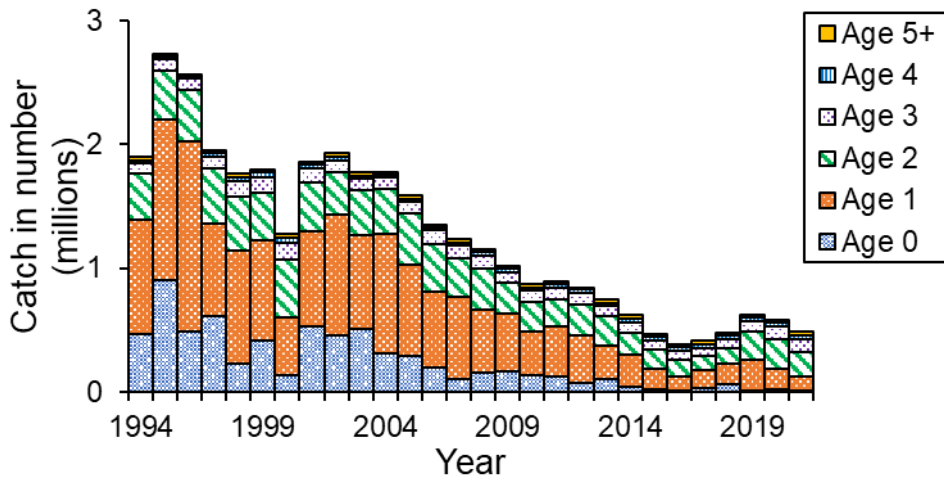


Fig. 3-2. Trends in catch in number at age

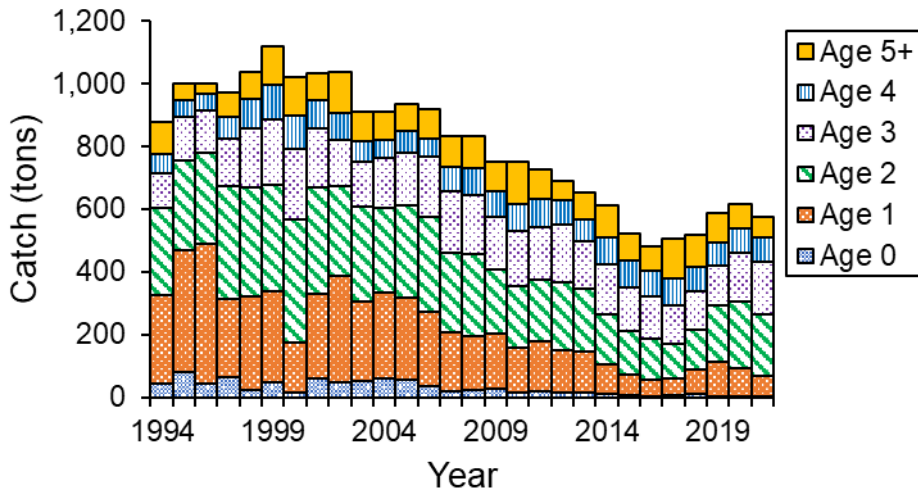


Fig. 3-3. Trends in catch in weight at age

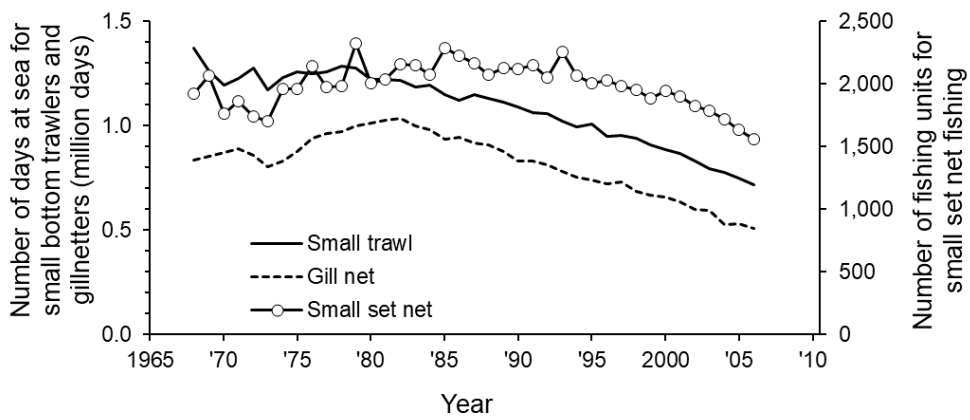


Fig. 3-4. Trends in effort for Small trawl fishery, Gill net fishery, and small set net fishery in the Seto Inland Sea area (up to 2006) based on Agricultural, Forestry and Fisheries Statistics

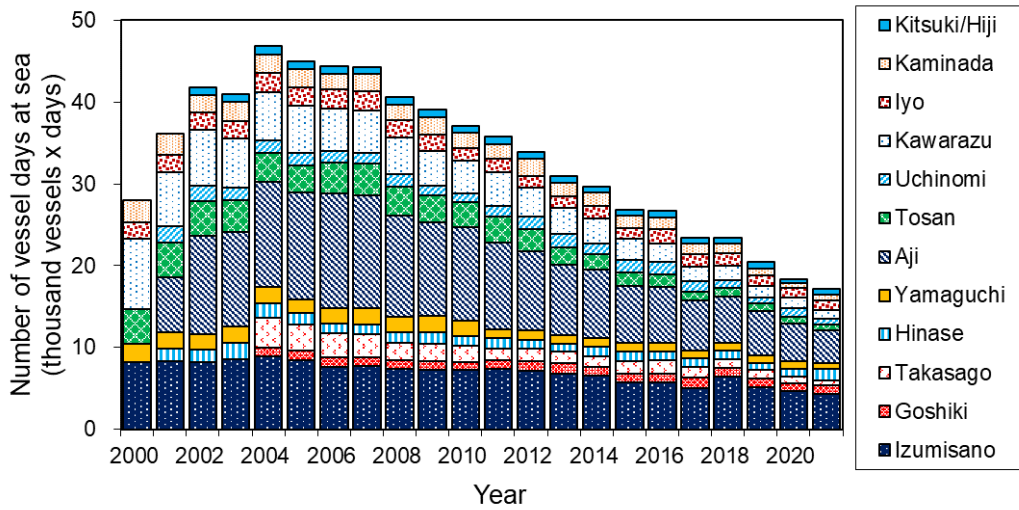


Fig. 3-5. Trends in number of vessels at sea for Small trawl fishery sample vessels and sample fisheries cooperatives

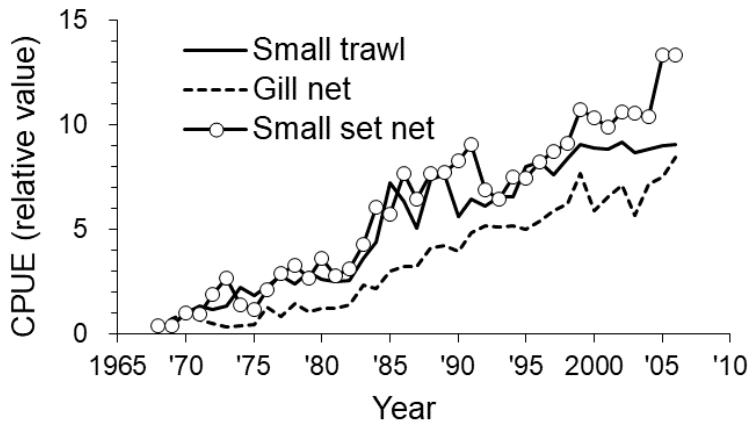


Fig. 4-1. Trends in CPUE of Small trawl fishery, Gill net fishery, and small set net fishery in the Seto Inland Sea area (up to 2006) based on Agriculture, Forestry and Fisheries Statistics. The value for 1970 was set to 1.

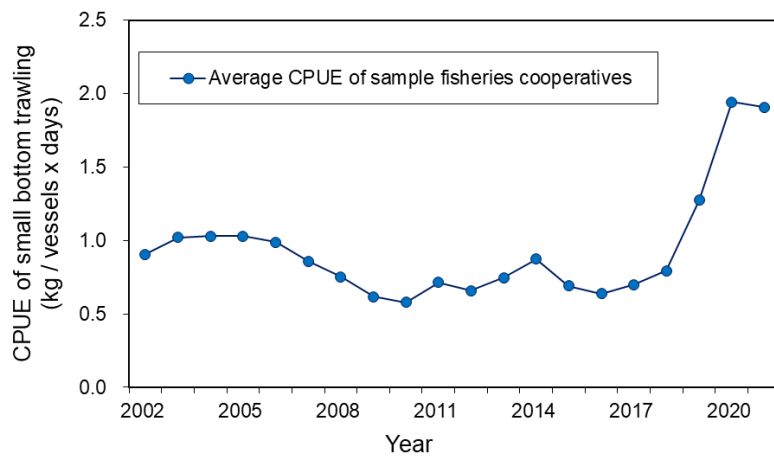


Fig. 4-2. Weighted average of CPUE of Small trawl fishery sample vessels and sample fisheries cooperatives (since 2002)

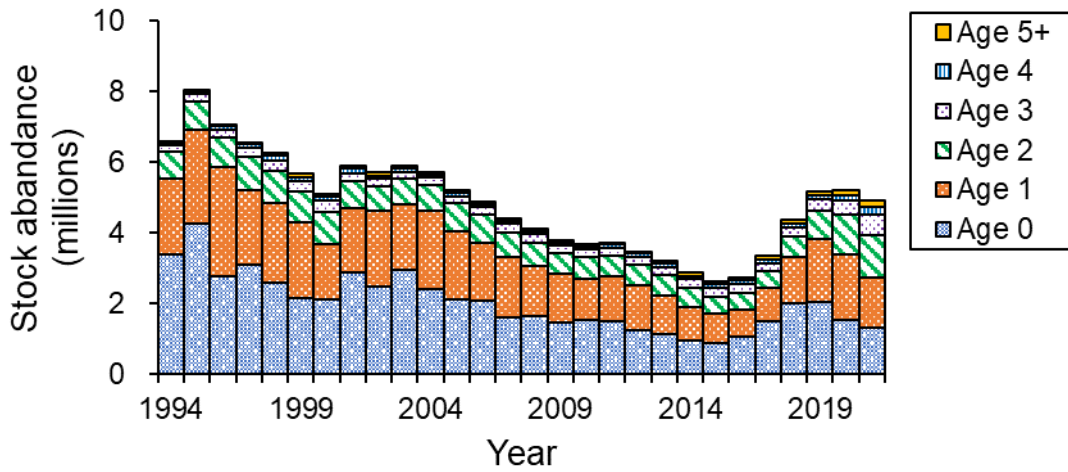


Fig. 4-3. Trends in stock abundance at age

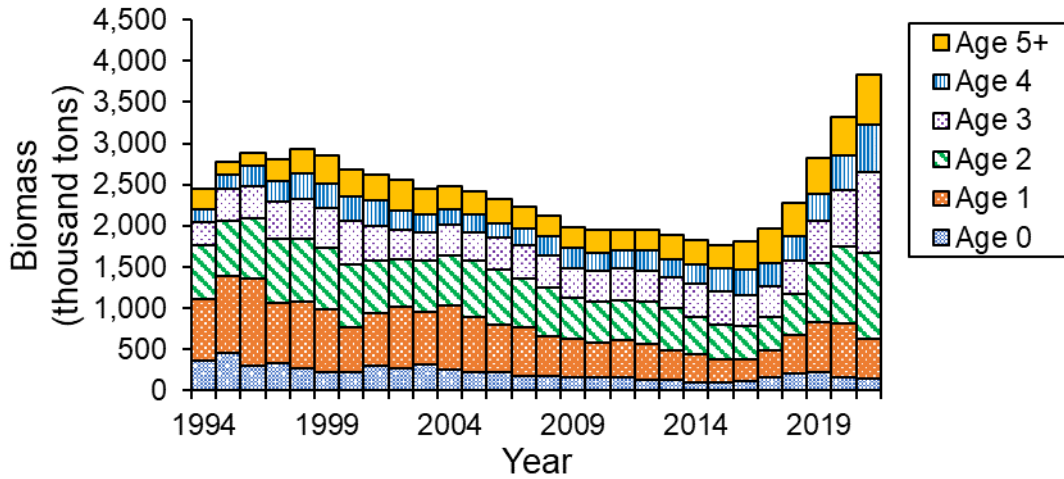


Fig. 4-4. Trends in biomass at age

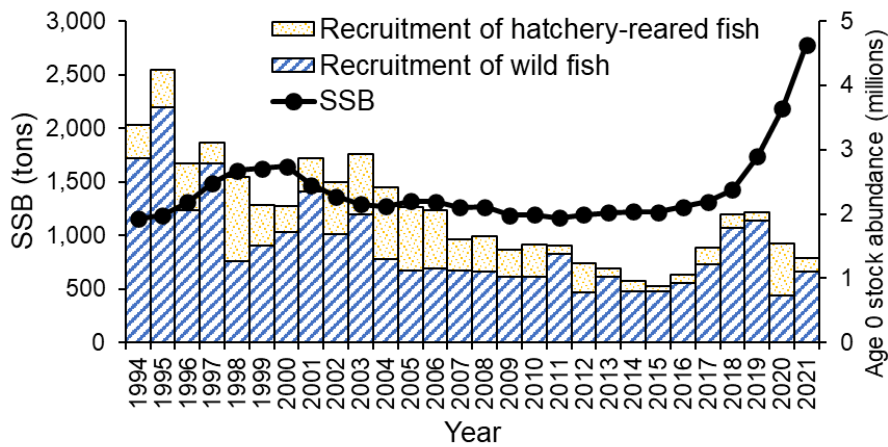


Fig. 4-5. Trends in SSB and recruitment

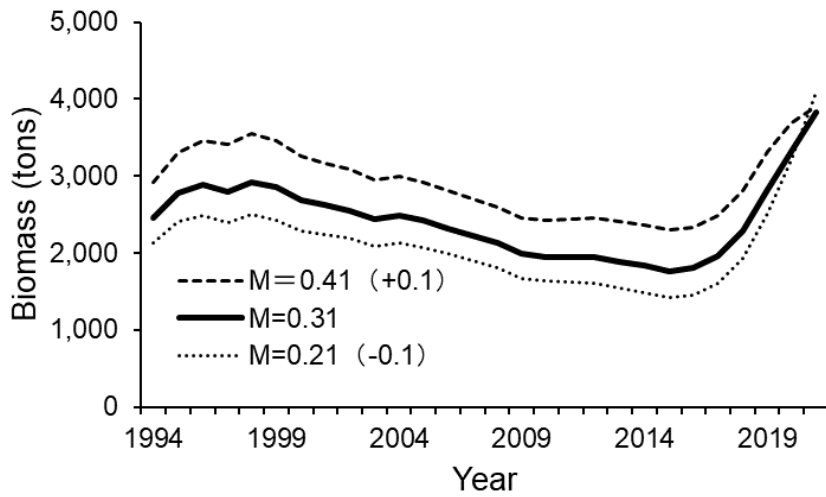


Fig. 4-6. Sensitivity analysis of biomass with natural mortality M

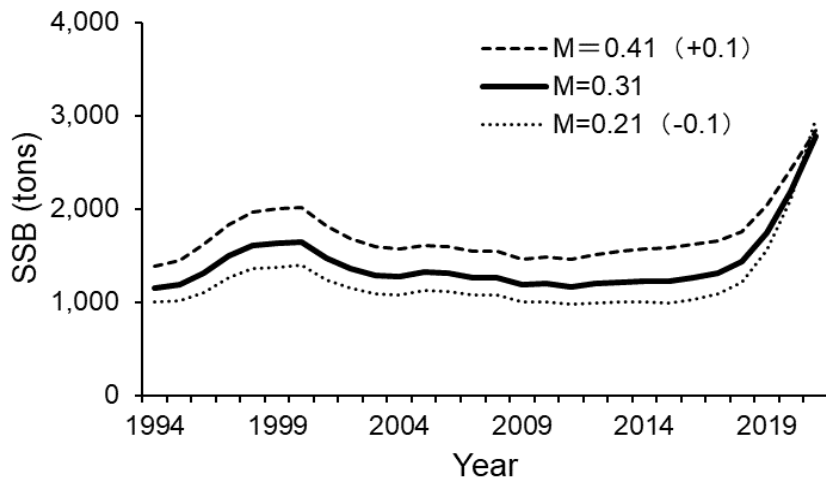


Fig. 4-7. Sensitivity analysis of SSB with natural mortality M

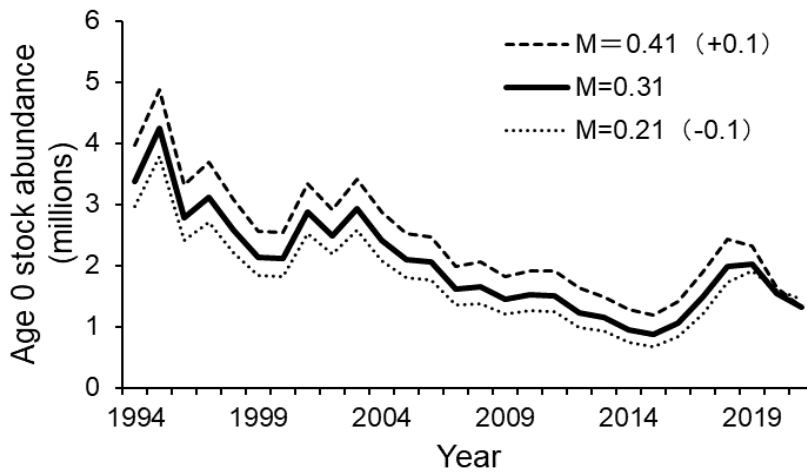


Fig. 4-8. Sensitivity analysis of age 0 stock abundance with natural mortality M

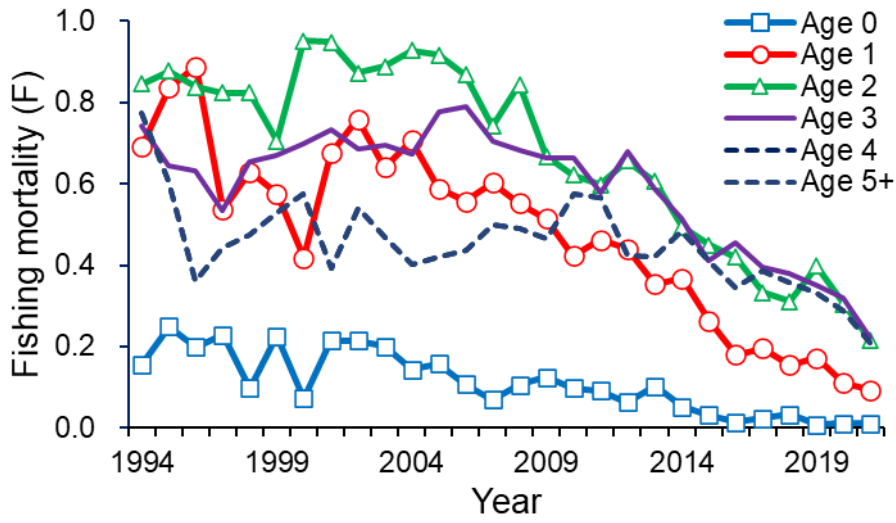


Fig. 4-9. Trends in fishing mortality F at age

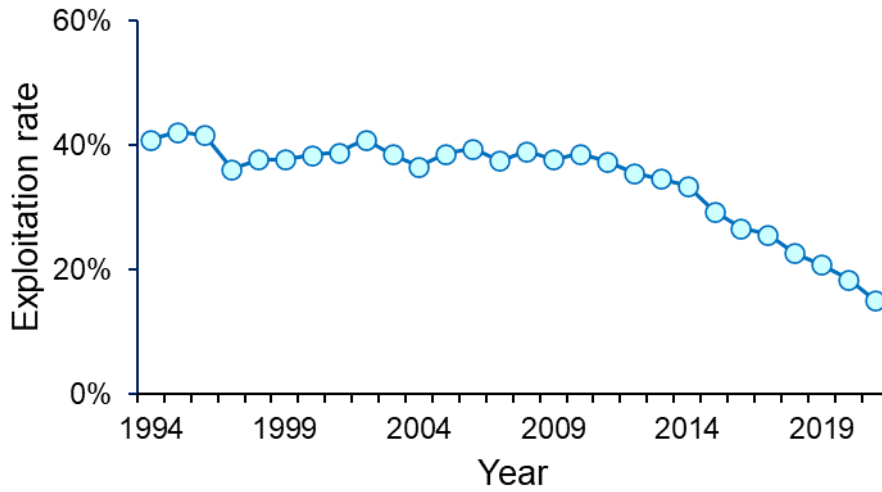


Fig. 4-10. Trends in exploitation rate

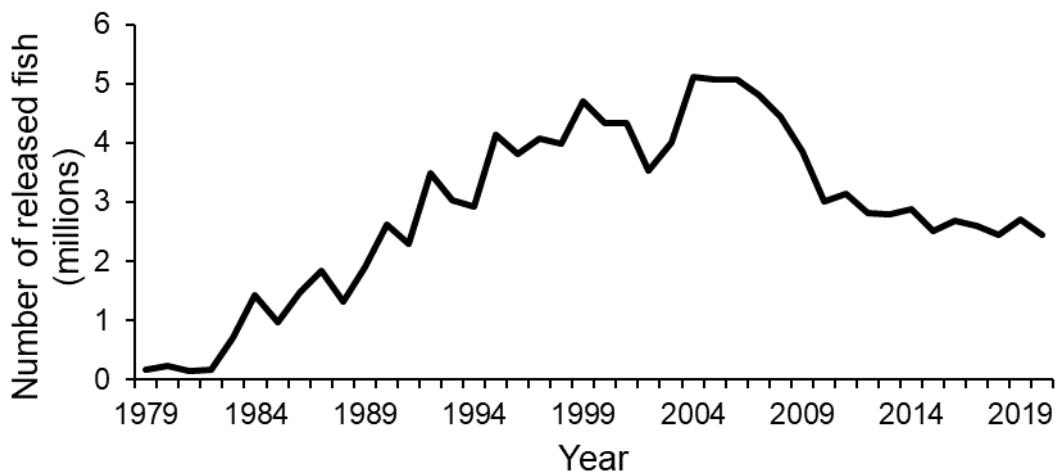


Fig. 4-11. Trends in number of released fish since 1979

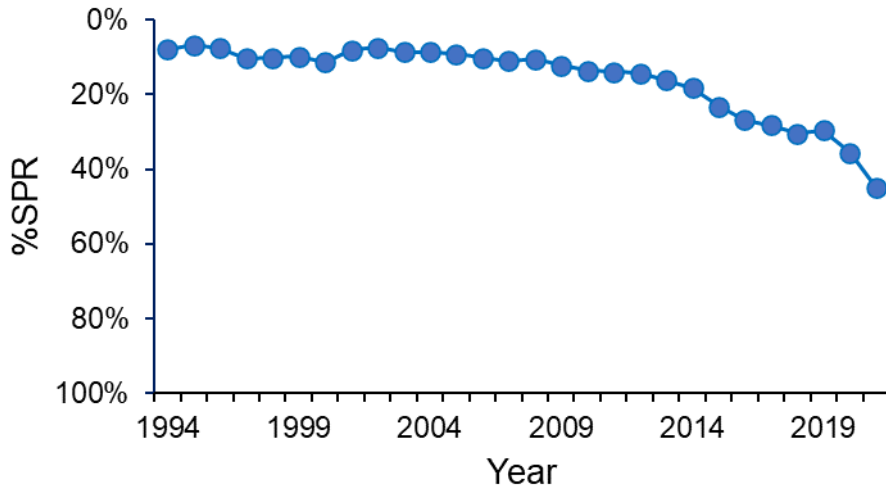


Fig. 4-12. Changes over time in %SPR value by each year. The %SPR indicates the ratio of SSB with fishing to SSB without fishing. When F is high (low), then %SPR is smaller (larger).

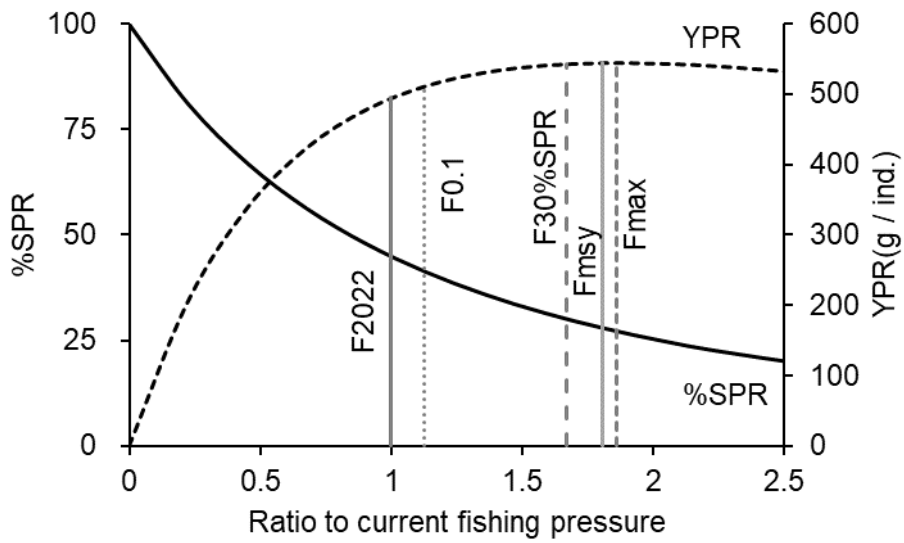
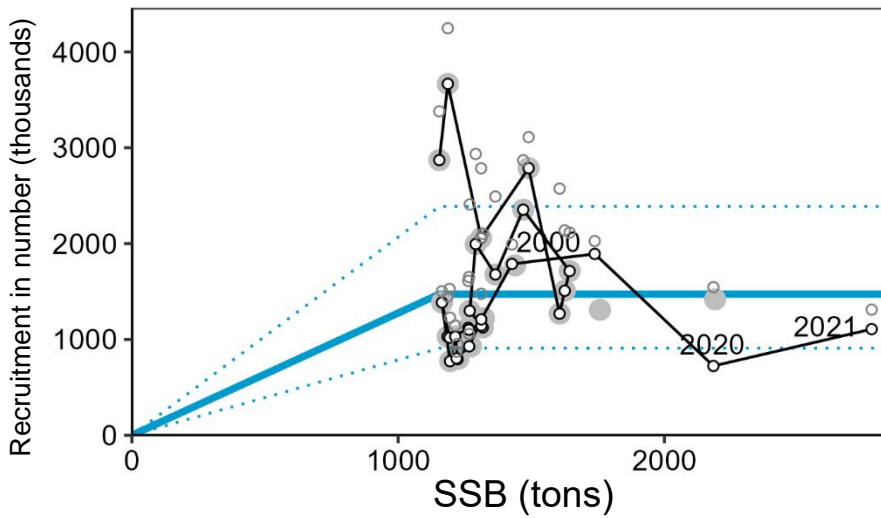


Fig. 4-13. Relationship between current fishing pressure (F2022) and YPR and %SPR



Function: HS, autocorrelation: 1, optimization method: L2, AICc: 20.68

Fig. 4-14. Relationship between SSB and recruitment. The solid blue line is the stock-recruitment relationship for this stock and the dotted lines above and below represent the interval estimated to contain 90% of observed data in the assumed stock-recruitment relationship. The parameters of the stock-recruitment relationship model are based on the values presented in the Research Institute Meeting (Yamashita et al. 2021) held in September 2021, and the solid gray circles indicate the SSB and recruitment at the time of this stock-recruitment relationship estimate. The white circles indicate estimated SSB and recruitment number between 1994 and 2021 used in this stock assessment, black represents wild only, and gray represents the recruitment number when released stock is taken into account. The numbers in the figure indicate the cohort (birth year) of the recruited stock.

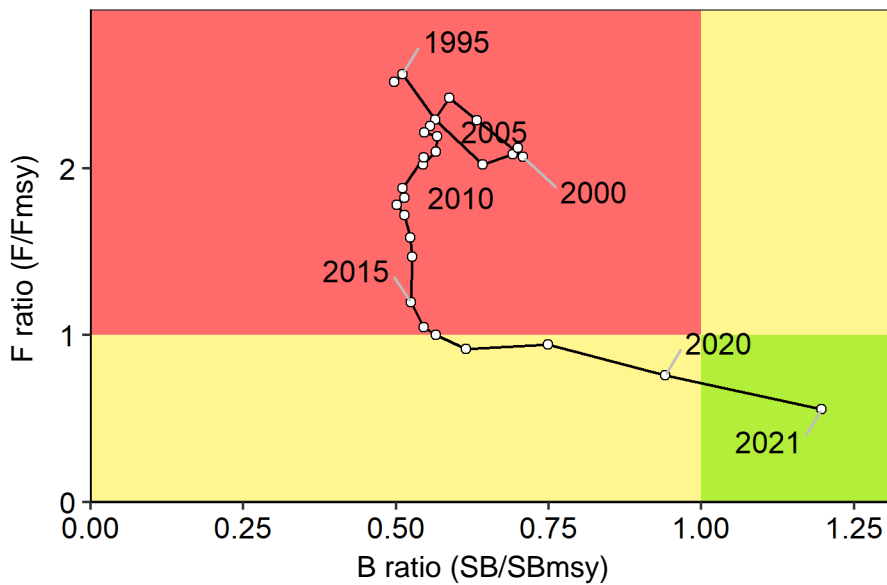


Fig. 4-15. Kobe plot

Table 3-1. Catch (tons) of Seto Inland Sea stock of bastard halibut

Year	Kii Strait	Osa ka Bay	Hari ma- nada	Bisa n- Seto	Hiuc hi- nada	Bing o- Geiy o*	Aki- nada	Iyo- nada	Suo- nada	Total
1952	18	10	102	106	43		14	45	39	377
1953	9	4	54	77	40		7	36	38	265
1954	16	5	111	84	88		8	69	72	453
1955	8	2	79	90	74		15	79	84	431
1956	25	3	110	61	38		13	46	95	391
1957	11	2	44	27	38		22	39	16	199
1958	7	1	39	2	23		19	47	3	141
1959	4	1	20	12	28		13	75	48	201
1960	0	0	18	10	19		13	66	77	203
1961	7	0	12	0	14		19	31	100	183
1962	3	1	8	7	18		17	37	45	136
1963	6	1	11	2	19		11	15	23	88
1964	4	0	16	1	14		16	33	8	92
1965	11	1	18	3	13		14	37	1	98
1966	10	1	9	27	18		11	30	8	114
1967	12	1	5	16	25		3	21	5	88
1968	16	1	11	52	24		4	34	10	152
1969	28	0	6	32	31		8	34	9	148
1970	15	1	10	13	88		6	49	21	203
1971	37	0	12	16	96		29	15	23	228
1972	28	0	4	17	96		21	22	19	207
1973	27	4	9	26	117		10	27	9	229
1974	21	3	43	29	119		7	26	15	263
1975	23	7	64	18	87		7	16	9	231
1976	24	4	13	15	119		15	118	15	323
1977	38	6	19	43	158		10	85	14	373
1978	34	6	16	51	39	126	62	49	33	416
1979	30	9	21	69	60	144	58	56	19	468
1980	65	8	22	58	76	120	44	24	15	431
1981	63	9	24	58	87	100	19	35	21	415
1982	67	6	22	40	76	107	42	55	21	435
1983	56	9	57	49	92	132	73	98	11	577
1984	78	15	44	41	109	154	62	125	27	655
1985	80	32	207	54	127	155	77	207	9	948
1986	74	22	204	50	134	182	93	119	10	888
1987	71	19	71	50	145	198	102	93	8	757
1988	76	9	222	49	181	255	100	102	23	1,017
1989	65	44	155	58	206	304	114	92	4	1,042
1990	65	34	106	57	141	240	96	89	4	832
1991	80	25	185	56	155	221	103	108	3	936
1992	91	26	144	53	155	181	116	117	5	888
1993	95	40	135	56	138	168	118	135	16	901
1994	106	37	126	76	160	114	127	122	8	876
1995	118	26	151	95	238	179	104	83	8	1,000
1996	101	21	159	99	167	222	107	111	12	1,000
1997	87	23	157	108	143	230	108	96	20	973
1998	87	44	185	99	113	276	96	108	31	1,039

Table 3-1. (continued) Catch (tons) of Seto Inland Sea stock of bastard halibut

Year	Kii Strait	Osa ka Bay	Hari ma- nada	Bisa n- Seto	Hiuc hi- nada	Bing o- Geiy o*	Aki- nada	Iyo- nada	Suo- nada				Total
1999	86	40	209	88	93	258	116	191	37				1,118
2000	74	25	167	92	104	266	93	158	44				1,023
2001	76	27	153	74	89	333	92	156	33				1,033
2002	71	52	135	109	242	174	93	142	21				1,039
2003	58	39	155	92	230	137	93	70	37				912
2004	69	44	158	120	106	234	71	59	50				911
2005	81	41	142	107	120	280	73	58	31				934
Year	Wak aya ma	Osa ka	Hyo go	Oka yam a	Hiro shim a	Yam aguc hi	Tok ushi ma	Kag awa	Ehi me	Fuk uoka	Oita	Total	
2006	26	8	130	28	65	46	36	125	410	1	44	918	
2007	13	8	118	33	72	35	31	100	383	1	41	835	
2008	17	6	106	32	122	28	23	108	350	1	39	831	
2009	13	7	119	31	109	29	24	102	288	1	27	750	
2010	12	5	124	30	97	31	28	90	301	1	32	751	
2011	14	7	118	32	98	31	27	90	274	1	36	728	
2012	11	7	132	31	84	28	28	79	259	1	32	691	
2013	9	8	129	32	80	28	22	76	239	1	30	654	
2014	13	5	143	35	70	29	28	80	180	1	30	613	
2015	10	6	88	29	63	29	22	79	168	0	27	520	
2016	9	6	90	29	57	24	20	75	146	1	25	482	
2017	12	7	104	27	38	26	24	74	142	1	49	504	
2018	15	7	119	30	38	29	25	79	147	1	30	519	
2019	13	18	156	35	30	33	31	85	144	1	41	588	
2020**	11	25	180	37	32	32	31	87	137	1	42	615	
2021***	17	24	165	28	31	33	47	78	107	2	44	576	

* The catch in weight of Bingo-Geyo Seto was included in Hiuchi-nada until 1977, and has been separated since 1978

** Total catch in weight for 2020 has now been finalized, and has been revised from last year's approximate value

*** Total catch in 2021 is an approximate value

Table 3-2. CPUE (kg/number of days at sea) and effort (number of days at sea) of Small trawl fishery and Gill net fishery, and CPUE (tons/fishing units) and effort (fishing units) of small set net fishery; up to 2006

Year	Small trawl		Gill net		Small set net	
	CPUE	Number of fishing days	CPUE	Number of fishing days	CPUE	Number of fishing units
1968	0.04	1,373,678	0.01	834,635	0.00	1,924
1969	0.04	1,261,958	0.04	852,001	0.00	2,068
1970	0.09	1,196,851	0.05	873,766	0.01	1,767
1971	0.12	1,226,470	0.03	889,297	0.00	1,863
1972	0.10	1,275,259	0.02	857,899	0.01	1,740
1973	0.12	1,173,183	0.02	806,015	0.01	1,705
1974	0.19	1,231,561	0.02	830,603	0.01	1,961
1975	0.16	1,259,258	0.02	877,888	0.01	1,959
1976	0.20	1,250,443	0.06	940,174	0.01	2,141
1977	0.24	1,257,197	0.04	960,817	0.01	1,974
1978	0.20	1,285,936	0.07	973,048	0.02	1,985
1979	0.25	1,277,913	0.05	998,513	0.01	2,328
1980	0.22	1,222,827	0.06	1,014,695	0.02	2,007
1981	0.21	1,221,183	0.06	1,027,415	0.01	2,033
1982	0.22	1,219,748	0.07	1,034,989	0.02	2,156
1983	0.31	1,187,619	0.11	1,000,991	0.02	2,150
1984	0.37	1,196,887	0.11	979,294	0.03	2,071
1985	0.62	1,148,855	0.15	933,918	0.03	2,289
1986	0.54	1,123,191	0.16	946,653	0.04	2,224
1987	0.43	1,151,227	0.16	919,477	0.03	2,162
1988	0.63	1,129,380	0.20	909,193	0.04	2,077
1989	0.65	1,114,723	0.21	876,758	0.04	2,130
1990	0.48	1,092,348	0.20	829,300	0.04	2,118
1991	0.55	1,064,092	0.24	833,030	0.05	2,153
1992	0.52	1,058,620	0.26	815,062	0.04	2,054
1993	0.56	1,023,712	0.25	783,039	0.03	2,255
1994	0.56	994,086	0.25	753,895	0.04	2,067
1995	0.68	1,006,915	0.25	741,748	0.04	2,008
1996	0.70	950,983	0.27	720,932	0.04	2,030
1997	0.65	952,662	0.29	729,140	0.04	1,980
1998	0.71	938,420	0.31	683,685	0.05	1,956
1999	0.77	909,769	0.38	665,695	0.05	1,883
2000	0.76	885,218	0.29	658,172	0.05	1,943
2001	0.75	868,645	0.32	635,932	0.05	1,902
2002	0.78	831,926	0.35	599,106	0.05	1,828
2003	0.74	796,401	0.28	593,780	0.05	1,789
2004	0.75	775,278	0.35	528,797	0.05	1,720
2005	0.77	748,152	0.37	529,370	0.07	1,639
2006	0.77	718,757	0.41	506,802	0.07	1,562

* Due to changes in the aggregated content of fishery catch statistics, it is no longer possible to continue collecting effort and calculating CPUE in this format for 2007 and beyond. Accordingly, since 2002, we have shifted to referring to the effort and CPUE of sample vessels and sample fishing cooperatives, as shown in Tables 3 and 4.

Table 3-3. Total number of Small trawl fishery sample vessels and sample fisheries cooperative (vessels*days)

Year	Izumisano (Osaka)	Goshiki (Hyogo)	Takasago (Hyogo)	Hinase (Okayama)	Total of 5 sample vessels in Yamaguchi prefecture	Aji (Kagawa)	Tosan (Kagawa)	Uchinomi (Kagawa)	Kawarazu (Ehime)	Iyo (Ehime)	Kaminada (Ehime)	Kitsuki, Hiji (Oita)	Total
2002	8,223			1,559	1,843	12,052	4,201	1,955	6,731	2,110	2,225	865	41,764
2003	8,526			2,093	1,925	11,606	3,856	1,571	5,932	2,206	2,304	993	41,012
2004	8,957	1,049	3,570	1,824	1,995	12,910	3,530	1,463	5,921	2,337	2,296	985	45,437
2005	8,460	1,157	3,152	1,467	1,644	13,014	3,319	1,536	5,839	2,165	2,335	931	45,019
2006	7,592	1,243	2,878	1,175	1,962	13,932	3,857	1,429	5,155	2,299	1,970	855	44,347
2007	7,722	1,101	2,773	1,224	2,035	13,693	3,887	1,397	5,171	2,313	2,091	879	44,286
2008	7,331	1,071	2,189	1,262	1,904	12,398	3,507	1,513	4,466	2,129	1,940	919	40,629
2009	7,302	1,039	2,052	1,420	2,090	11,339	3,406	1,084	4,260	2,050	2,122	906	39,070
2010	7,281	977	1,978	1,177	1,841	11,499	2,973	1,153	3,937	1,614	1,768	897	37,095
2011	7,403	1,002	1,487	1,226	1,083	10,580	3,210	1,285	4,096	1,661	1,858	897	35,788
2012	7,138	1,194	1,540	1,090	1,107	9,744	2,669	1,470	3,537	1,457	2,155	852	33,953
2013	6,846	1,241	1,454	880	1,091	8,582	2,191	1,558	3,201	1,484	1,614	811	30,953
2014	6,541	1,087	1,314	1,125	1,099	8,358	1,842	1,308	3,051	1,530	1,663	766	29,684
2015	5,709	1,035	1,546	1,224	1,086	6,977	1,567	1,510	2,622	1,257	1,630	722	26,885
2016	5,698	1,131	1,573	1,145	1,019	6,853	1,530	1,571	2,138	1,787	1,475	737	26,657
2017	5,070	1,229	1,303	1,022	992	6,132	1,077	1,250	1,857	1,467	1,346	710	23,455
2018	6,448	1,104	953	1,160	931	5,682	967	958	1,823	1,447	1,226	667	23,366
2019	5,165	982	1,089	890	921	5,357	956	787	1,416	1,251	849	783	20,446
2020	4,724	909	835	974	833	4,693	809	1,004	1,297	1,194	546	562	18,380
2021	4,360	1,013	648	1,309	810	3,937	755	705	1,087	1,129	716	655	17,124

Table 4-1. Trends in weighted average CPUE (kg/vessel/days) of Small trawl fishery sample vessels and sample fisheries cooperatives

Year	Izumisano (Osaka)	Goshiki (Hyogo)	Takasago (Hyogo)	Hinase (Okayama)	Total of 5 sample vessels in Yamaguchi prefecture	Aji (Kagawa)	Tosan (Kagawa)	Uchinomi (Kagawa)	Kawarazu (Ehime)	Iyo (Ehime)	Kaminada (Ehime)	Kitsuki, Hiji (Oita)	Total
2002	0.31			1.25	0.38	1.14	0.07	0.14	0.22	0.90	0.74	0.42	0.91
2003	0.36			1.18	0.31	1.29	0.09	0.15	0.25	1.17	0.62	0.29	1.02
2004	0.30	0.67	0.36	1.09	0.45	1.39	0.05	0.25	0.43	0.91	0.24	0.37	1.03
2005	0.25	0.45	0.36	1.09	0.49	1.38	0.05	0.25	0.41	0.77	0.30	0.34	1.03
2006	0.34	1.19	0.49	0.50	0.39	1.26	0.05	0.23	0.49	1.10	0.25	0.60	0.99
2007	0.37	1.51	0.45	0.55	0.39	1.06	0.04	0.11	0.24	0.86	0.44	0.20	0.86
2008	0.18	1.00	0.23	0.87	0.27	0.90	0.03	0.06	0.30	0.86	0.68	0.19	0.75
2009	0.23	0.92	0.36	0.88	0.38	0.77	0.06	0.05	0.21	0.45	0.28	0.55	0.62
2010	0.18	0.41	0.33	1.17	0.24	0.66	0.04	0.06	0.37	0.61	0.35	0.55	0.58
2011	0.20	0.40	0.20	1.35	0.45	0.85	0.02	0.08	0.36	0.52	0.17	0.50	0.71
2012	0.22	0.25	0.42	0.98	0.66	0.82	0.02	0.08	0.29	0.71	0.37	0.22	0.66
2013	0.31	0.31	0.37	1.33	0.57	0.95	0.02	0.07	0.57	0.50	0.30	0.31	0.75
2014	0.31	0.76	0.45	1.14	0.50	1.12	0.02	0.10	0.76	0.77	0.42	0.38	0.87
2015	0.32	0.85	0.41	1.17	0.63	0.68	0.01	0.10	0.78	0.57	0.82	0.36	0.69
2016	0.29	0.95	0.32	1.18	0.60	0.59	0.01	0.06	0.80	0.43	0.51	0.27	0.64
2017	0.34	0.37	0.22	1.17	0.69	0.66	0.02	0.06	0.62	0.71	1.15	0.62	0.70
2018	0.38	0.37	0.57	1.60	0.69	0.80	0.00	0.04	0.91	0.74	0.58	0.58	0.79
2019	1.33	0.57	0.88	2.80	1.25	0.79	0.02	0.05	1.10	0.71	0.93	0.22	1.27
2020	2.73	0.51	1.16	1.76	0.90	1.13	0.04	0.07	1.22	0.93	1.17	0.52	1.94
2021	2.68	0.34	1.42	0.89	1.55	1.24	0.08	0.15	1.30	0.81	0.79	0.38	1.91

Table 4-2. Results of stock analysis for Seto Inland Sea stock of bastard halibut

Year	Catch (tons)	Biomass (tons)	SSB (tons)	Recruitment in number (thousands)		Exploitation rate (%)	%SPR	F/F _{msy}
				Wild	Hatchery- reared fish			
1994	876	2,451	1,154	2,871	509	41	7.9	2.51
1995	1,000	2,773	1,186	3,667	580	42	6.6	2.56
1996	1,000	2,884	1,311	2,059	726	42	7.5	2.28
1997	973	2,803	1,490	2,787	324	36	10.4	2.02
1998	1,039	2,926	1,606	1,269	1,305	38	10.2	2.08
1999	1,118	2,851	1,625	1,508	630	38	9.9	2.12
2000	1,023	2,682	1,644	1,713	401	38	11.3	2.06
2001	1,033	2,620	1,470	2,354	516	39	8.0	2.28
2002	1,039	2,555	1,365	1,678	813	41	7.5	2.41
2003	912	2,443	1,291	1,995	940	39	8.6	2.25
2004	911	2,486	1,269	1,299	1,110	37	8.6	2.21
2005	934	2,419	1,318	1,125	976	39	9.2	2.18
2006	918	2,323	1,312	1,145	919	40	10.1	2.09
2007	835	2,228	1,263	1,121	490	37	11.0	2.02
2008	831	2,125	1,266	1,102	549	39	10.6	2.06
2009	750	1,988	1,186	1,028	420	38	12.3	1.88
2010	751	1,945	1,193	1,018	509	39	13.6	1.82
2011	728	1,944	1,164	1,385	117	37	13.9	1.78
2012	691	1,943	1,195	773	455	36	14.3	1.71
2013	654	1,887	1,214	1,029	116	35	16.1	1.58
2014	613	1,832	1,223	795	159	33	18.2	1.46
2015	520	1,768	1,219	802	69	29	23.2	1.19
2016	482	1,808	1,266	928	129	27	26.8	1.04
2017	504	1,960	1,312	1,209	268	26	28.1	0.99
2018	519	2,283	1,427	1,787	203	23	30.4	0.91
2019	588	2,820	1,738	1,892	134	21	29.6	0.94
2020	615	3,326	2,184	723	822	18	35.6	0.76
2021	576	3,827	2,778	1,107	203	15	44.9	0.55

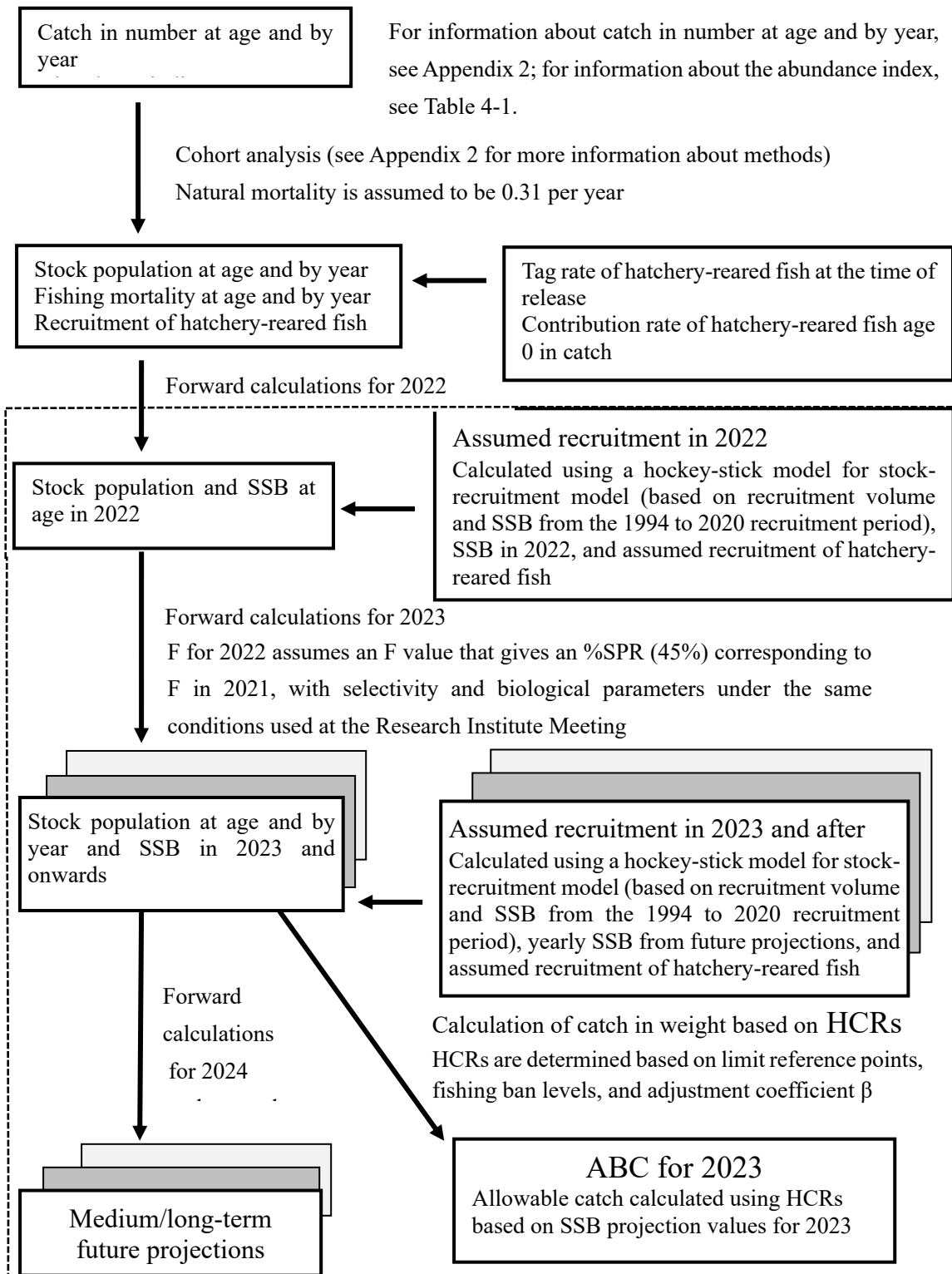
Recruitment in 2021 is an assumed value for both wild and hatchery-reared stock

Table 4-3. Number of released hatchery-reared fish, tag rate, contribution rate, and survival to recruitment of released fish

Release year	Number of released fish (thousands)	Contribution rate (%) without correction	Tag rate	Contribution rate (%) with correction	Survival to recruitment (age 0)
1979	161				
1980	227				
1981	140				
1982	171				
1983	719				
1984	1,431				
1985	966				
1986	1,462				
1987	1,840				
1988	1,314				
1989	1,897				
1990	2,616				
1991	2,293				
1992	3,486				
1993	3,031				
1994	2,919				
1995	4,134	13.7	1.00	13.7	0.14
1996	3,817	26.1	1.00	26.1	0.19
1997	4,078	10.4	1.00	10.4	0.08
1998	3,982	50.7	1.00	50.7	0.33
1999	4,695	27.0	0.92	29.5	0.13
2000	4,332	19.0	1.00	19.0	0.09
2001	4,327	18.0	1.00	18.0	0.12
2002	3,537	29.5	0.90	32.6	0.23
2003	4,001	28.8	0.90	32.0	0.23
2004	5,102	40.0	0.87	46.1	0.22
2005	5,079	41.0	0.88	46.5	0.19
2006	5,062	34.3	0.77	44.5	0.18
2007	4,817	22.9	0.75	30.4	0.10
2008	4,440	22.9	0.69	33.3	0.12
2009	3,856	22.4	0.77	29.0	0.11
2010	3,015	26.9	0.81	33.3	0.17
2011	3,144	6.1	0.79	7.8	0.04
2012	2,823	25.1	0.68	37.0	0.16
2013	2,789	7.2	0.71	10.1	0.04
2014	2,884	12.4	0.75	16.6	0.06
2015	2,516	4.8	0.60	7.9	0.03
2016	2,693	7.3	0.60	12.2	0.05
2017	2,592	6.1	0.34	18.1	0.10
2018	2,452	7.4	0.73	10.2	0.08
2019	2,702	3.0	0.46	6.6	0.05
2020	2,447	25.4	0.48	53.2	0.34
2021		4.3	0.39	11.1	—

The number of released fish in 2021 has not yet been determined, thus survival to recruitment has not been calculated.

Appendix 1 Flow of Stock Assessment



※ Information inside the dotted line box is based on discussion of reference points, HCRs, etc., by the stakeholder meeting.

http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/index.html

Appendix 2 Calculation Methods

(1) Estimation of catch in number at age and by year

Since 1994, monthly total length measurements by fishery type were conducted in sample fisheries cooperatives throughout the Seto Inland Sea, and the frequency composition for total length class by year and season for the Seto Inland Sea as a whole, weighted by the respective monthly catches, was obtained. Furthermore, using the total catch value by season of Seto Inland Sea, according to the proportion of catch by season in the sample fisheries cooperatives, in addition to the total length-weight relationships by sex, and the proportion of sexes by total length class by season, the frequency composition by total length class by season by year was converted to weight composition by total length class by sex by season by year.

Since 1995, age determination by otoliths and total length and weight measurements were conducted in various regions of the Seto Inland Sea to obtain age-length key (ALK) by sex by season (January to April, May to August, and September to December), sex ratio by total length class by season (Supplementary Table 2-1), and total length-weight relationship by sex. Weight composition by total length class by sex by season by age was calculated by applying ALK by sex by season to the weight composition by total length class by sex by season by year, which was then multiplied by the catch by season in the Seto Inland Sea and divided by the average body weight of each total length class by season by sex to calculate the catch in number at age by sex by season. Finally, the catch in number for males and females in each season was added together to obtain the catch in number by age group.

For the period from 1996 to 2005, the catch in number by set net fishery in the central sea area (statistical range: Hiroshima Prefecture, Hiuchi-nada in Kagawa Prefecture, and Hiuchi-nada in Ehime Prefecture) and those caught by others had been separately calculated, and then added together to obtain the total catch in number at age. The catch in number by set net fishery in the central area by age not calculated by the aforementioned method, was calculated by the weight composition by age and mean weight by age of the catches obtained from set net fishery in Hiuchi-nada in Kagawa Prefecture, and catch of set net fishery in the central sea area. The catch in number for other fisheries by age was calculated for the eastern area (statistical range: Wakayama, Osaka, Hyogo, Okayama, Tokushima, and Kagawa Prefecture excluding Hiuchi-nada), the central area excluding set net fishery, and the western area (statistical range: Yamaguchi, Iyo-nada in Ehime, Fukuoka, and Oita Prefectures) by the respective methods described above.

The sample fisheries cooperatives and types of fisheries from which data has been collected up to now are the respective Small trawl fishery in Izumisano (Osaka Prefecture), Kariya, Kobe City, Shiota, Yura, Asanoura, Bouze, Murotsuura, Takasago, Goshiki (Hyogo Prefecture), Kawarazu (Hiuchi-nada in Ehime Prefecture), Iyo and Kami-nada (Iyo-nada in Ehime Prefecture), the set net fishery in Ibuki, Ohama, Nio (Hiuchi-nada in Kagawa Prefecture) and Yuge (Hiuchi-nada in Ehime Prefecture), the Gill net fishery of Saijo (Hiuchi-nada in Ehime Prefecture), the Small trawl fishery and others in Tokuyama, Ube, Hofu (Yamaguchi Prefecture), and the Gill net, trap net and pole and line fisheries in Himejima, Kunimi, and Aki (Oita Prefecture).

(2) Biomass Estimation Method

Stock estimates were made using cohort analysis based on the catch in number at age and by year for the 28-year period from 1994 to 2021, for age 0 to 4 with age 5 and older as a plus group. For age 1 fish and older, January 1 was used as the starting date for age. Since age 0 fish join the fishery in the autumn, population size was estimated as of October 1. These were summed for all ages to obtain the population size in year y .

The biological parameters used in the cohort calculations are shown in Supplementary Table 2-2. Natural mortality (M_a) was estimated using the method of Tauchi and Tanaka (Tanaka 1960), assuming a maximum age of 8 (Watanabe et al. 2004). For age 0 fish, M_a was divided by one-quarter of a year, assuming recruitment to be October 1. For the conversion from stock abundance to biomass, the average weight by age, including females and males, obtained from the results of precision measurements (age-assessed) of catch from 1995 to 2020 was used.

For the stock assessment of this stock in previous years, the average weight by age was newly updated using the weight data of age-assessed individuals based on the precision measurement data from 1995 to the most recent year, and then, those values were multiplied by the stock population at age for each year going back from the most recent year to recalculate biomass at age. However, due to an issue highlighted regarding the annual change of this parameter, in the FY 2021 stock assessment, it was decided not to update the parameters for the next five years (see Yamashita et al. 2022 and Appendix 2 (2)).

The average body weight of the actual catch was calculated by dividing the catch in weight at age determined in Appendix 2 (1) for each year by catch in number at age. However, for 2003 and earlier, the average weight values in Supplementary Table 2-2 was multiplied by a factor where the sum of the “catch in number multiplied by body weight” equals the actual catch in weight.

The stock population ($N_{a,y}$) and fishing mortality ($F_{a,y}$) of fish age (0 to 3) in year y , excluding the most recent year, were calculated using the following equations. (Hiramatsu 2001).

$$N_{a,y} = N_{a+1,y+1} \exp(M_a) + C_{a,y} \exp\left(\frac{M_a}{2}\right) \quad (0 \leq a \leq 3) \quad (1)$$

$$F_{a,y} = -\ln\left(1 - \frac{C_{a,y} \exp\left(\frac{M_a}{2}\right)}{N_{a,y}}\right) \quad (0 \leq a \leq 3) \quad (2)$$

$C_{a,y}$ is the catch in number in year (y) at age (a).

Fish age 5 and older were deemed the plus group (5+), and, assuming fishing mortality to be equal for the age 4 and age 5+ groups, and stock abundance for fish age 4+ was obtained using the following equations.

$$N_{4,y} = \left(\frac{C_{4,y}}{(C_{4,y} + C_{5+,y})}\right) N_{5+,y+1} \exp(M_4) + C_{4,y} \exp\left(\frac{M_4}{2}\right) \quad (3)$$

$$N_{5+,y} = \left(\frac{C_{5+,y}}{C_{4,y}} \right) N_{4,y} \quad (4)$$

The stock population in the most recent year was obtained using the following equation.

$$N_{a,y} = \frac{C_{a,y}}{1 - \exp(-F_{a,y})} \exp\left(\frac{M_a}{2}\right) \quad (1 \leq a \leq 5^+) \quad (5)$$

F in the latest year (terminal F) was calculated with F4,y as an unknown parameter, assumed to be F5+,y = F4,y, and F0,y to F3,y to be equal to the ratio of F at age 4+ compared to the ratio of the average F for the previous 3 years (2018 to 2020 average).

$$F_{a,y} = \left(\frac{\sum_{b=1}^3 F_{a,y-b}}{\sum_{b=1}^3 F_{4,y-b}} \right) F_{4,y} \quad (1 \leq a \leq 3) \quad (6)$$

F4,y was estimated using tuned cohort analysis based on the observed CPUE in year y, u_y (the CPUE (kg/vessel/day) calculated from the catch of sample vessels and the total number of active number of vessels at sea, see Table 4-1 for values, weighted by the catch of each port or vessel) (Hiramatsu 2001). For u_y that has undergone log transformation, the following random variables for normal distribution were assumed.

$$\ln(u_y) = \ln q \sum_a (s_{a,y} N_{a,y} W_a)^b + \varepsilon_y \quad \text{Here, } \varepsilon_y \sim N(0, \sigma^2) \quad (7)$$

In this equation, $s_{a,y}$ and W_a are the selectivity (ratio of age a to the maximum F by age in that year) and the average weight at age a, respectively, and b is a parameter representing the nonlinear relationship between the tuning index value and the target biomass size.

The fishing gear efficiency, q, is obtained using equation (8), where the number of years of the survey used for tuning is T years.

$$q = \exp\left(\frac{\sum_y \ln(u_y) - b \sum_y \ln(\sum_a (s_{a,y} N_{a,y} W_a)^b)}{T}\right) \quad (8)$$

Parameters F4,y and b that minimize equation (9) to create the greatest consistency in trends between the observed values for CPUE and the theoretical values of CPUE obtained from biomass estimated through a tuning cohort analysis were estimated.

$$SS = \sum_y \left(\ln(u_y) - \ln\left(q \sum_a (s_{a,y} N_{a,y} W_a)^b\right) \right)^2 \quad (9)$$

In this equation, the nonlinear parameter b was estimated to be 1.45.

SSB was obtained by multiplying the age 1 and older stock population by the average weight and maturity rate (f_{ra} , Supplementary Table 2-2). Note that the maturity rates used in these equations are for females.

$$SB_y = \sum_{a=1}^{5+} N_{a,y} W_a f r_a \quad (10)$$

Details of the results of the cohort analysis estimated from the above calculations are presented in Supplementary Table 2-3.

(3) Estimation of contribution rates and recruitment from wild fish and hatchery-reared fish

Estimation of the contribution rate of hatchery-released fish in age 0 catch, and the stratification of age 0 stock ($N_{0,y}$) into the number of wild recruits (R_{ny}), and the number of hatchery-reared recruits (R_{ay}) was performed using the following process.

Abnormal deposition of black pigmentation occurs on the blind side in many individuals of hatchery-reared bastard halibut. These hypermelanic individuals were used in place of tagging to hatchery-reared fish, and the rate of hypermelanic individuals (= tag rate) at the time of release was collected by each prefecture. Since the rate of hypermelanic individuals varies from year to year and from production facility to production facility, and the number of hatchery-released fish also varies, it is desirable to calculate a weighted average of the number of hatchery-released fish for each prefecture and ocean area, or to divide the areas and treat the tag rates for each location separately when calculating the tag rate which represents the entire Seto Inland Sea. However, we have not been able to survey and understand the tag rates in all release areas (7 prefectures in 2021: Wakayama, Osaka, Hyogo, Hiroshima, Yamaguchi, Kagawa, and Ehime), and we do not have sufficient data to conduct a detailed study for each area. Therefore, a simple average of the tag rates of the prefectures for which we have data is used as the tag rate for the Seto Inland Sea as a whole.

Next, using the results of precision measurements of bastard halibut catches obtained from each prefecture in the Biological Information Survey, we estimated the rate of hypermelanic individuals in age 0 catch by assessing whether individuals were hypermelanic on the blind side. The Seto Inland Sea is divided into three areas: eastern (Kii Strait, Osaka Bay, Harima-nada, Bisan-Seto), central (Hiuchi-nada, Bingo-Geiyo Seto, Aki-nada), and western (Iyo-nada, Suo-nada). The number of samples measured and the number of hypermelanic individuals in each area are counted, then the (apparent) rate of hypermelanic individuals for each area is calculated. The number of prefectures where hypermelanic individuals were identified among age 0 fish in 2021 was six: Osaka, Hyogo, Yamaguchi, Kagawa, Ehime (Toyo and Chuyo), and Oita. However, the number of prefectures where hypermelanic individuals were examined by precision measurement would increase if fish age 1 and older were included, but at this point, calculations are not ready to reflect the different tag rates in each year for multiple recruitment periods, so only age 0 fish were assessed. Next, a simple average of the rates of hypermelanic individuals in the three areas is taken (= apparent contribution rate for the Seto Inland Sea as a whole), and this value is divided by the tag rate obtained at the time of the release of

hatchery-reared fish to obtain the corrected contribution rate for hatchery-reared fish for the Seto Inland Sea as a whole.

The recruitment from hatchery-reared fish in year y (Ra_y) was calculated by the following equation.

$$Ra_y = N_{0,y} \times \text{corrected contribution rate} \quad (11)$$

Survival to recruitment of released fish is the ratio of all hatchery-released fish that survive and are added to the stock of fishery, which is calculated using the equation below.

$$\text{survival to recruitment of released fish} = \frac{Ra_y}{\text{the number of hatchery-released fish at year } y} \quad (12)$$

Therefore, equation (12) can be rewritten as the product of the survival to recruitment multiplied by the number of hatchery-released fish.

$$Ra_y = \text{the number of hatchery-released fish at year } y \times \text{survival to recruitment} \quad (13)$$

We then subtracted Ra_y from $N_{0,y}$ to obtain the number of wild recruits (Rn_y) for each year except the most recent year.

$$Rn_y = N_{0,y} - Ra_y \quad (14)$$

(4) Analysis of YPR and SPR

The yield per recruitment (YPR) and spawning per recruitment (SPR) were calculated using the following equations.

$$YPR = \sum_{a=1}^{\infty} S_a W_a \exp(-M_a/2) (1 - \exp(-F_a)) \quad (15)$$

$$SPR = \sum_{a=0}^{\infty} fra S_a W_a \quad (16)$$

$$S_{a+1} = S_a \exp(-F_a - M_a) \quad (\text{Provided that } S_0=1) \quad (17)$$

In these equations, S_a is the survival rate at age a , and fra is the ratio of mature females at age a .

Although the life span was assumed to be 8 years when estimating M of this stock, YPR and SPR calculations were performed without obtaining the life span in accordance with the settings used in MSY calculations.

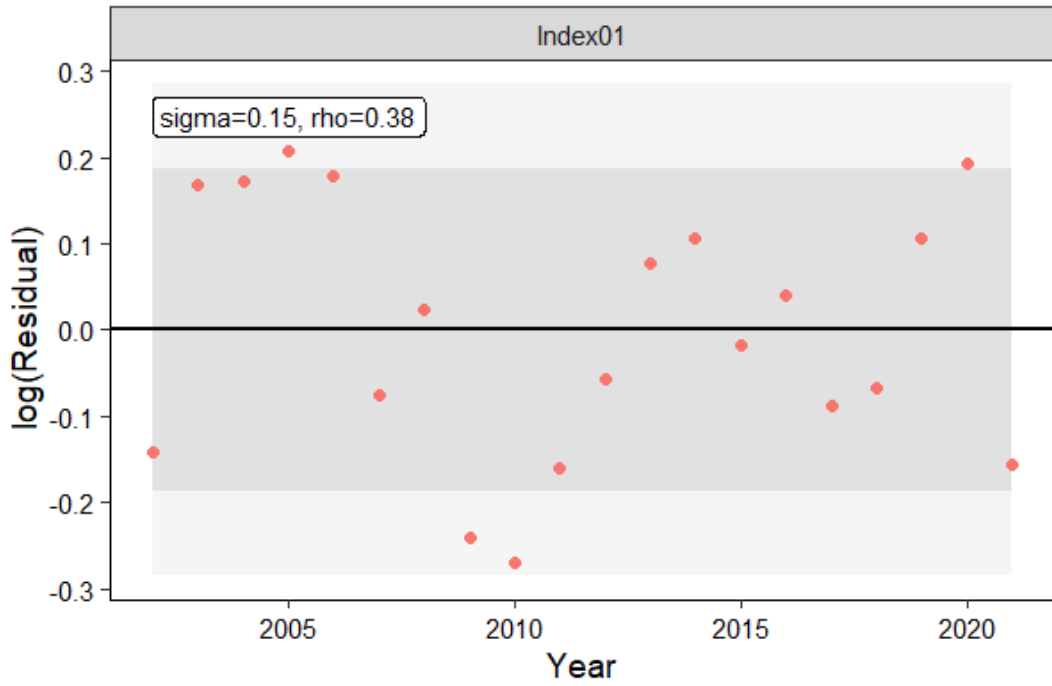
(5) Model Diagnosis Results

The robustness of the statistical validity of the VPA and assumptions used for this stock assessment were diagnosed according to the Stock Assessment Model Diagnostic Procedures and Data Provision Guidelines (FY 2022) (FRA-SA2022-ABCWG02-03).

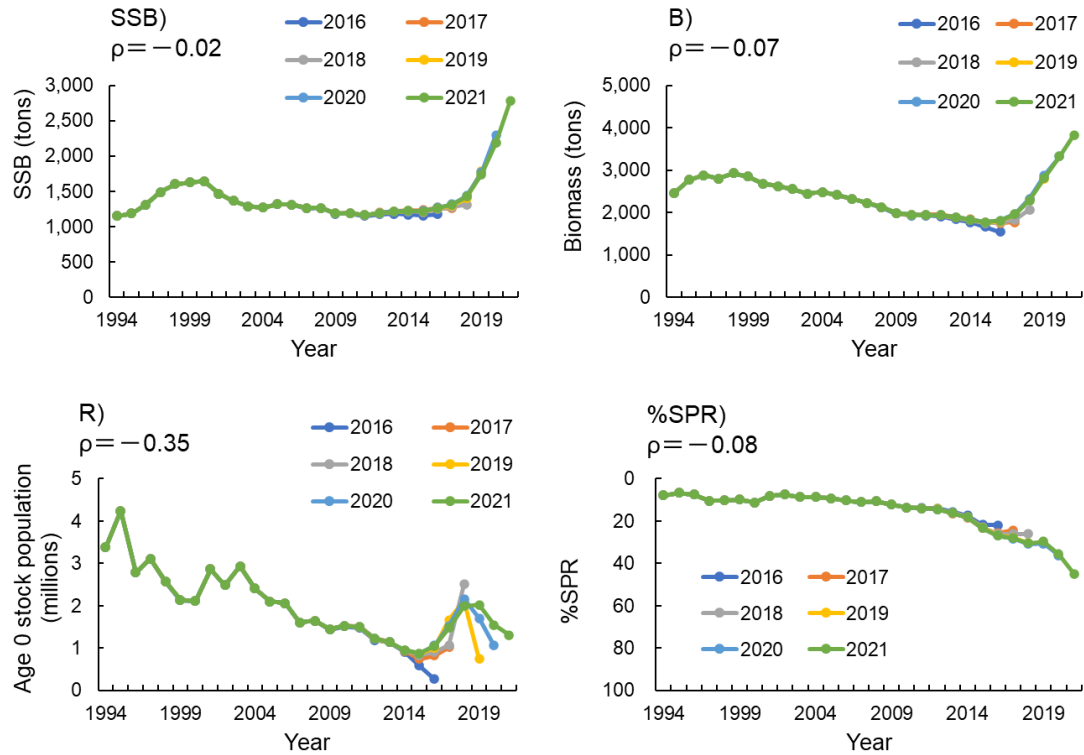
The residuals of tuning are shown in Supplementary Fig. 2-1. Although there is a tendency here for the values to remain somewhat similar, it was considered that there is no significant bias. Retrospective analysis (Supplementary Fig. 2-2) also showed no significant changes in SSB, or fishing pressure (%SPR), although the age 0 stock population tended to be revised upward as data were added and updated.

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<https://abchan.fra.go.jp/digests2021/details/202161.pdf> (last accessed 13 July 2022)



Supplementary Fig. 2-1. Residual plots for VPA with tuning



Supplementary Fig. 2-2. Results of retrospective analysis of spawning stock biomass (SSB), biomass (B), age 0 stock population (R), and %SPR. The numbers in the legend show the final year of VPA.

Supplementary Table 2-1. Age-length key and sex ratio (January to April, May to August)

Female												
Total length class (mm)	January to April					Percentage of females	May to August					Percentage of females
	Age 1	Age 2	Age 3	Age 4	Age 5+		Age 1	Age 2	Age 3	Age 4	Age 5+	
0~40	1.00	0.00	0.00	0.00	0.00	0.50	1.00	0.00	0.00	0.00	0.00	0.50
40~80	1.00	0.00	0.00	0.00	0.00	0.50	1.00	0.00	0.00	0.00	0.00	0.50
80~120	1.00	0.00	0.00	0.00	0.00	0.50	1.00	0.00	0.00	0.00	0.00	0.50
120~160	1.00	0.00	0.00	0.00	0.00	0.50	1.00	0.00	0.00	0.00	0.00	0.50
160~200	1.00	0.00	0.00	0.00	0.00	0.30	1.00	0.00	0.00	0.00	0.00	0.25
200~240	1.00	0.00	0.00	0.00	0.00	0.47	0.92	0.06	0.02	0.00	0.00	0.34
240~280	0.98	0.02	0.00	0.00	0.00	0.38	0.91	0.09	0.00	0.00	0.00	0.47
280~320	0.85	0.15	0.00	0.00	0.00	0.35	0.85	0.15	0.00	0.00	0.00	0.47
320~360	0.49	0.48	0.03	0.00	0.00	0.33	0.69	0.31	0.00	0.00	0.00	0.39
360~400	0.16	0.79	0.05	0.00	0.00	0.23	0.27	0.68	0.04	0.00	0.00	0.31
400~440	0.06	0.85	0.09	0.00	0.00	0.49	0.03	0.87	0.10	0.00	0.00	0.53
440~480	0.03	0.83	0.13	0.01	0.00	0.77	0.01	0.86	0.12	0.01	0.00	0.71
480~520	0.02	0.64	0.33	0.01	0.00	0.79	0.00	0.64	0.32	0.05	0.00	0.76
520~560	0.01	0.33	0.61	0.04	0.01	0.77	0.00	0.30	0.58	0.11	0.01	0.78
560~600	0.01	0.18	0.60	0.17	0.04	0.76	0.01	0.18	0.60	0.17	0.04	0.76
600~640	0.00	0.06	0.49	0.35	0.10	0.83	0.00	0.06	0.49	0.35	0.10	0.83
640~680	0.00	0.01	0.29	0.42	0.27	0.89	0.00	0.01	0.29	0.42	0.27	0.89
680~720	0.00	0.01	0.13	0.39	0.47	0.96	0.00	0.01	0.13	0.39	0.47	0.96
720~760	0.00	0.00	0.05	0.25	0.70	0.98	0.00	0.00	0.05	0.25	0.70	0.98
760~800	0.00	0.00	0.01	0.10	0.88	1.00	0.00	0.00	0.01	0.10	0.88	1.00
800~840	0.00	0.00	0.03	0.00	0.97	1.00	0.00	0.00	0.03	0.00	0.97	1.00
840~880	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00
880~920	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00
920~960	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00
960~	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00

Male												
Total length class (mm)	January to April					Percentage of females	May to August					Percentage of females
	Age 1	Age 2	Age 3	Age 4	Age 5+		Age 1	Age 2	Age 3	Age 4	Age 5+	
0~40	1.00	0.00	0.00	0.00	0.00		1.00	0.00	0.00	0.00	0.00	
40~80	1.00	0.00	0.00	0.00	0.00		1.00	0.00	0.00	0.00	0.00	
80~120	1.00	0.00	0.00	0.00	0.00		1.00	0.00	0.00	0.00	0.00	
120~160	1.00	0.00	0.00	0.00	0.00		1.00	0.00	0.00	0.00	0.00	
160~200	1.00	0.00	0.00	0.00	0.00		1.00	0.00	0.00	0.00	0.00	
200~240	0.99	0.01	0.00	0.00	0.00		0.99	0.01	0.00	0.00	0.00	
240~280	0.86	0.14	0.00	0.00	0.00		0.87	0.13	0.00	0.00	0.00	
280~320	0.61	0.38	0.01	0.00	0.00		0.70	0.29	0.01	0.00	0.00	
320~360	0.19	0.77	0.04	0.00	0.00		0.23	0.69	0.07	0.00	0.00	
360~400	0.04	0.85	0.10	0.00	0.00		0.04	0.83	0.10	0.02	0.00	
400~440	0.05	0.61	0.31	0.02	0.01		0.02	0.53	0.40	0.04	0.01	
440~480	0.01	0.36	0.52	0.09	0.02		0.00	0.38	0.38	0.14	0.10	
480~520	0.01	0.16	0.41	0.22	0.20		0.00	0.18	0.26	0.32	0.23	
520~560	0.00	0.09	0.42	0.22	0.28		0.00	0.03	0.35	0.30	0.32	
560~600	0.01	0.03	0.31	0.37	0.28		0.01	0.03	0.31	0.37	0.28	
600~640	0.00	0.02	0.08	0.40	0.51		0.00	0.02	0.08	0.40	0.51	
640~680	0.00	0.00	0.05	0.24	0.71		0.00	0.00	0.05	0.24	0.71	
680~720	0.00	0.00	0.00	0.33	0.67		0.00	0.00	0.00	0.33	0.67	
720~	0.00	0.00	0.00	0.00	1.00		0.00	0.00	0.00	0.00	1.00	

Supplementary Table 2-1. (continued) Age-length key and sex ratio (September to December)
(continued)

Female Total length class (mm)	September to December						Percentage of females
	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+	
0~40	1.00	0.00	0.00	0.00	0.00	0.00	0.50
40~80	1.00	0.00	0.00	0.00	0.00	0.00	0.50
80~120	1.00	0.00	0.00	0.00	0.00	0.00	0.50
120~160	1.00	0.00	0.00	0.00	0.00	0.00	0.46
160~200	1.00	0.00	0.00	0.00	0.00	0.00	0.52
200~240	1.00	0.00	0.00	0.00	0.00	0.00	0.58
240~280	0.95	0.05	0.00	0.00	0.00	0.00	0.59
280~320	0.70	0.27	0.02	0.00	0.00	0.00	0.46
320~360	0.26	0.68	0.07	0.00	0.00	0.00	0.32
360~400	0.00	0.94	0.04	0.01	0.00	0.00	0.40
400~440	0.00	0.88	0.11	0.01	0.00	0.00	0.57
440~480	0.00	0.73	0.27	0.00	0.00	0.00	0.76
480~520	0.00	0.65	0.32	0.03	0.00	0.00	0.83
520~560	0.00	0.31	0.53	0.13	0.03	0.00	0.76
560~600	0.00	0.01	0.18	0.60	0.17	0.04	0.76
600~640	0.00	0.00	0.06	0.49	0.35	0.10	0.83
640~680	0.00	0.00	0.01	0.29	0.42	0.27	0.89
680~720	0.00	0.00	0.01	0.13	0.39	0.47	0.96
720~760	0.00	0.00	0.00	0.05	0.25	0.70	0.98
760~800	0.00	0.00	0.00	0.01	0.10	0.88	1.00
800~840	0.00	0.00	0.00	0.03	0.00	0.97	1.00
840~880	0.00	0.00	0.00	0.00	0.00	1.00	1.00
880~920	0.00	0.00	0.00	0.00	0.00	1.00	1.00
920~960	0.00	0.00	0.00	0.00	0.00	1.00	1.00
960~	0.00	0.00	0.00	0.00	0.00	1.00	1.00

Male Total length class (mm)	September to December					
	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+
0~40	1.00	0.00	0.00	0.00	0.00	0.00
40~80	1.00	0.00	0.00	0.00	0.00	0.00
80~120	1.00	0.00	0.00	0.00	0.00	0.00
120~160	1.00	0.00	0.00	0.00	0.00	0.00
160~200	1.00	0.00	0.00	0.00	0.00	0.00
200~240	0.99	0.01	0.00	0.00	0.00	0.00
240~280	0.88	0.12	0.01	0.00	0.00	0.00
280~320	0.42	0.54	0.04	0.00	0.00	0.00
320~360	0.06	0.84	0.10	0.01	0.00	0.00
360~400	0.01	0.76	0.18	0.01	0.02	0.00
400~440	0.00	0.71	0.22	0.01	0.01	0.04
440~480	0.00	0.33	0.44	0.04	0.11	0.07
480~520	0.00	0.14	0.36	0.36	0.00	0.14
520~560	0.00	0.10	0.10	0.20	0.10	0.50
560~600	0.00	0.01	0.03	0.31	0.37	0.28
600~640	0.00	0.00	0.02	0.08	0.40	0.51
640~680	0.00	0.00	0.00	0.05	0.24	0.71
680~720	0.00	0.00	0.00	0.00	0.33	0.67
720~	0.00	0.00	0.00	0.00	0.00	1.00

Supplementary Table 2-2. Average body weight, maturity rate, and natural mortality (M) by age used in cohort calculations

Age	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+
Average weight (g)	107	349	848	1,660	2,651	3,853
Maturity Ratio	0	0.042	0.750	0.818	1.000	1.000
Natural mortality	0.0781	0.3125	0.3125	0.3125	0.3125	0.3125

Supplementary Table 2-3. Stock analysis results (1994 to 2003)

Catch at age in number(thousands)										
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	468	899	484	612	230	415	141	532	462	513
Age 1	923	1,297	1,542	749	915	808	462	764	974	752
Age 2	374	395	412	443	434	386	466	398	338	369
Age 3	78	98	96	95	121	121	138	112	91	89
Age 4	26	24	24	29	37	40	41	32	31	25
Age 5+	30	16	10	21	24	31	32	22	35	25
Total	1,899	2,728	2,569	1,948	1,762	1,801	1,280	1,861	1,931	1,774
Catch at age (tons)										
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	44	82	43	63	23	46	15	58	49	53
Age 1	281	387	447	250	300	292	159	271	338	254
Age 2	277	286	291	360	346	340	392	343	285	303
Age 3	113	139	133	151	189	209	227	188	151	143
Age 4	60	53	53	73	93	109	107	87	83	65
Age 5+	101	52	34	77	88	122	123	87	133	95
Total	876	1,000	1,000	973	1,039	1,118	1,023	1,033	1,039	912
Fishing mortality at age										
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	0.156	0.249	0.199	0.229	0.098	0.226	0.072	0.214	0.214	0.201
Age 1	0.693	0.836	0.888	0.536	0.630	0.575	0.419	0.675	0.759	0.640
Age 2	0.846	0.878	0.839	0.824	0.824	0.706	0.951	0.949	0.873	0.888
Age 3	0.741	0.646	0.634	0.533	0.653	0.671	0.698	0.733	0.686	0.695
Age 4	0.773	0.605	0.360	0.444	0.474	0.529	0.575	0.391	0.539	0.469
Age 5+	0.773	0.605	0.360	0.444	0.474	0.529	0.575	0.391	0.539	0.469
% SPR	7.9	6.6	7.5	10.4	10.2	9.9	11.3	8.0	7.5	8.6
F/Fmsy	2.51	2.56	2.28	2.02	2.08	2.12	2.06	2.28	2.41	2.25
Stock abundance at age (thousands)										
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	3,380	4,246	2,785	3,111	2,574	2,138	2,114	2,870	2,491	2,935
Age 1	2,159	2,676	3,062	2,110	2,288	2,159	1,578	1,820	2,142	1,860
Age 2	766	790	849	922	903	891	888	759	678	734
Age 3	174	241	240	268	296	290	322	251	215	207
Age 4	56	61	92	93	115	113	108	117	88	79
Age 5+	65	41	41	68	76	87	86	80	98	79
Total	6,600	8,054	7,069	6,572	6,252	5,677	5,097	5,898	5,712	5,894
Biomass at age (tons)										
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	360	453	297	331	274	228	225	306	265	313
Age 1	753	933	1,068	736	798	753	550	635	747	648
Age 2	650	669	719	781	766	756	753	644	575	622
Age 3	289	399	399	445	491	481	534	417	357	344
Age 4	149	161	245	247	305	299	287	311	234	210
Age 5+	251	158	156	261	291	335	331	308	376	306
Total	2,451	2,773	2,884	2,803	2,926	2,851	2,682	2,620	2,555	2,443
Exploitation rate (%)	35.7	36.1	34.7	34.7	35.5	39.2	38.1	39.4	40.7	37.3
SSB at age (tons)Year										
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	0	0	0	0	0	0	0	0	0	0
Age 1	32	39	45	31	34	32	23	27	31	27
Age 2	487	502	540	586	575	567	565	483	431	467
Age 3	236	327	326	364	402	394	437	341	292	281
Age 4	149	161	245	247	305	299	287	311	234	210
Age 5+	251	158	156	261	291	335	331	308	376	306
Total	1,154	1,186	1,311	1,490	1,606	1,625	1,644	1,470	1,365	1,291
RPS (ind./kg)	2.49	3.09	1.57	1.87	0.79	0.93	1.04	1.60	1.23	1.55
Average body weight of catch (g)										
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	93	91	89	102	100	111	106	108	106	103
Age 1	305	298	290	334	328	362	345	354	347	337
Age 2	741	726	705	813	797	880	840	861	844	820
Age 3	1,451	1,420	1,380	1,591	1,560	1,723	1,645	1,686	1,651	1,606
Age 4	2,318	2,269	2,205	2,542	2,492	2,752	2,627	2,693	2,638	2,565
Age 5+	3,369	3,297	3,205	3,694	3,622	4,000	3,819	3,914	3,834	3,728

Supplementary Table 2-3. (continued) Stock analysis results (2004 to 2013)

Catch at age in number(thousands)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 0	310	295	201	103	158	162	137	126	72	107
Age 1	962	735	607	665	505	473	349	405	387	272
Age 2	371	412	388	312	335	244	238	218	243	232
Age 3	93	96	109	104	102	90	91	89	96	85
Age 4	21	24	21	26	29	28	30	31	29	25
Age 5+	21	21	23	23	21	22	27	23	18	22
Total	1,778	1,583	1,349	1,232	1,150	1,019	873	893	845	743
Catch at age (tons)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 0	60	57	35	20	23	28	16	19	14	16
Age 1	275	262	237	185	170	174	140	157	136	129
Age 2	268	295	304	256	265	204	199	198	214	200
Age 3	160	167	192	196	189	168	174	167	185	151
Age 4	58	70	57	79	84	85	88	91	78	69
Age 5+	89	83	93	99	100	92	134	95	63	89
Total	911	934	918	835	831	750	751	728	691	654
Fishing mortality at age										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 0	0.144	0.158	0.107	0.069	0.105	0.124	0.098	0.091	0.063	0.103
Age 1	0.706	0.589	0.557	0.604	0.552	0.514	0.422	0.462	0.441	0.354
Age 2	0.928	0.917	0.867	0.742	0.844	0.667	0.621	0.598	0.657	0.606
Age 3	0.673	0.778	0.789	0.706	0.682	0.665	0.664	0.578	0.680	0.588
Age 4	0.403	0.419	0.437	0.500	0.489	0.464	0.574	0.566	0.424	0.421
Age 5+	0.403	0.419	0.437	0.500	0.489	0.464	0.574	0.566	0.424	0.421
% SPR	8.6	9.2	10.1	11.0	10.6	12.3	13.6	13.9	14.3	16.1
F/Fmsy	2.21	2.18	2.09	2.02	2.06	1.88	1.82	1.78	1.71	1.58
Stock abundance at age (thousands)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 0	2,408	2,101	2,064	1,611	1,651	1,449	1,527	1,502	1,228	1,145
Age 1	2,221	1,929	1,659	1,715	1,391	1,375	1,184	1,280	1,268	1,066
Age 2	717	802	783	695	686	586	601	568	590	597
Age 3	221	207	234	241	242	216	220	236	228	224
Age 4	76	82	70	78	87	90	81	83	97	85
Age 5+	73	72	75	68	65	68	73	63	61	75
Total	5,716	5,195	4,885	4,408	4,122	3,782	3,685	3,732	3,472	3,192
Biomass at age (tons)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 0	257	224	220	172	176	154	163	160	131	122
Age 1	774	673	579	598	485	479	413	446	442	372
Age 2	608	680	664	589	582	497	510	481	500	506
Age 3	367	344	389	399	402	358	365	392	379	371
Age 4	200	219	185	207	230	237	215	220	257	225
Age 5+	280	279	287	263	250	262	279	244	234	291
Total	2,486	2,419	2,323	2,228	2,125	1,988	1,945	1,944	1,943	1,887
Exploitation rate (%)	36.6	38.6	39.5	37.5	39.1	37.7	38.6	37.5	35.6	34.7
SSB at age (tons)Year										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 0	0	0	0	0	0	0	0	0	0	0
Age 1	33	28	24	25	20	20	17	19	19	16
Age 2	456	510	498	442	436	373	382	361	375	380
Age 3	300	282	318	327	329	293	299	321	310	304
Age 4	200	219	185	207	230	237	215	220	257	225
Age 5+	280	279	287	263	250	262	279	244	234	291
Total	1,269	1,318	1,312	1,263	1,266	1,186	1,193	1,164	1,195	1,214
RPS (ind./kg)	1.02	0.85	0.87	0.89	0.87	0.87	0.85	1.19	0.65	0.85
Average body weight of catch (g)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 0	192	192	172	197	144	171	119	155	194	149
Age 1	286	356	391	278	337	367	400	388	352	475
Age 2	723	716	783	823	792	837	835	905	883	860
Age 3	1,731	1,745	1,756	1,881	1,844	1,873	1,904	1,885	1,923	1,775
Age 4	2,718	2,895	2,720	3,008	2,927	2,986	2,898	2,960	2,730	2,792
Age 5+	4,345	3,914	4,110	4,299	4,671	4,232	4,960	4,071	3,494	4,012

Supplementary Table 2-3. (continued) Stock analysis results (2014 to 2021)

Catch at age in number (thousands)								
Year	2014	2015	2016	2017	2018	2019	2020	2021
Age 0	47	26	15	32	63	15	17	14
Age 1	252	166	110	147	163	241	167	107
Age 2	183	150	138	116	132	235	246	201
Age 3	82	71	71	63	68	79	96	101
Age 4	30	30	30	29	29	30	34	35
Age 5+	25	22	22	29	27	27	26	25
Total	619	465	384	416	481	626	587	483

Catch at age (tons)								
Year	2014	2015	2016	2017	2018	2019	2020	2021
Age 0	11	5	3	6	12	4	3	3
Age 1	92	66	52	54	76	111	88	63
Age 2	161	139	130	110	126	180	214	199
Age 3	159	139	136	123	126	126	155	167
Age 4	88	88	84	86	77	74	79	78
Age 5+	102	83	78	127	103	94	75	65
Total	613	520	482	504	519	588	615	576

Fishing mortality at age								
Year	2014	2015	2016	2017	2018	2019	2020	2021
Age 0	0.053	0.032	0.014	0.023	0.033	0.008	0.011	0.011
Age 1	0.368	0.264	0.180	0.196	0.154	0.172	0.111	0.093
Age 2	0.494	0.450	0.420	0.333	0.310	0.397	0.304	0.215
Age 3	0.515	0.412	0.456	0.395	0.379	0.352	0.319	0.223
Age 4	0.485	0.412	0.345	0.386	0.358	0.332	0.288	0.207
Age 5+	0.485	0.412	0.345	0.386	0.358	0.332	0.288	0.207
%SPR	18.2	23.2	26.8	28.1	30.4	29.6	35.6	44.9
F/Fmsy	1.46	1.19	1.04	0.99	0.91	0.94	0.76	0.55

Stock abundance at age (thousands)								
Year	2014	2015	2016	2017	2018	2019	2020	2021
Age 0	953	871	1,057	1,477	1,990	2,026	1,545	1,310
Age 1	955	837	780	964	1,334	1,781	1,860	1,413
Age 2	548	484	470	477	579	837	1,097	1,218
Age 3	238	244	226	226	250	311	411	592
Age 4	91	104	118	105	111	125	160	219
Age 5+	77	76	87	106	105	111	124	156
Total	2,862	2,616	2,739	3,354	4,371	5,190	5,197	4,907

Biomass at age (tons)								
Year	2014	2015	2016	2017	2018	2019	2020	2021
Age 0	102	93	113	157	212	216	165	140
Age 1	333	292	272	336	465	621	648	493
Age 2	464	410	399	404	491	709	930	1,033
Age 3	396	405	374	375	415	516	683	982
Age 4	241	276	314	277	295	332	424	580
Age 5+	296	291	336	410	405	426	477	600
Total	1,832	1,768	1,808	1,960	2,283	2,820	3,326	3,827
Exploitation rate (%)	33.5	29.4	26.7	25.7	22.7	20.9	18.5	15.1

SSB at age (tons) Year								
Year	2014	2015	2016	2017	2018	2019	2020	2021
Age 0	0	0	0	0	0	0	0	0
Age 1	14	12	11	14	20	26	27	21
Age 2	348	307	299	303	368	532	697	775
Age 3	324	332	306	307	339	422	558	803
Age 4	241	276	314	277	295	332	424	580
Age 5+	296	291	336	410	405	426	477	600
Total	1,223	1,219	1,266	1,312	1,427	1,738	2,184	2,778
RPS (ind./kg)	0.65	0.66	0.73	0.92	1.25	1.09	0.33	0.40

Average body weight of catch (g)								
Year	2014	2015	2016	2017	2018	2019	2020	2021
Age 0	226	177	201	171	187	251	184	205
Age 1	367	397	472	366	464	459	527	593
Age 2	883	926	942	949	953	765	870	988
Age 3	1,936	1,975	1,922	1,944	1,866	1,594	1,612	1,653
Age 4	2,959	2,937	2,825	2,993	2,680	2,463	2,323	2,231
Age 5+	4,019	3,796	3,583	4,343	3,798	3,504	2,847	2,623

Appendix 3 Proposed Reference Points and Proposed Fishing Ban Level

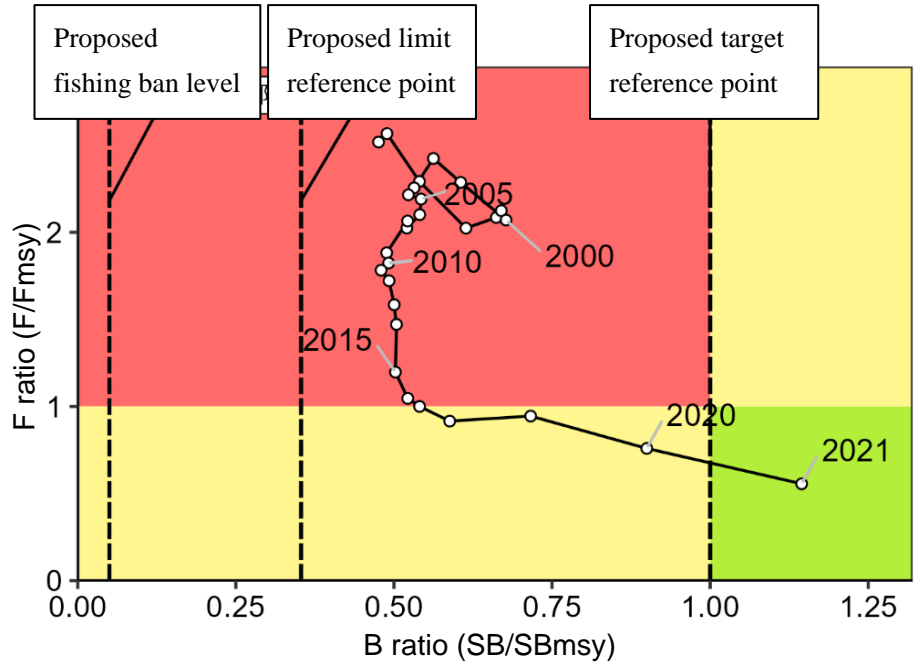
The Research Institute Meeting held in September 2021 proposed adoption of the following: SSB required for MSY (SB_{msy}: 2,400 tons) as a target reference point (SB_{target}), SSB required for 60% MSY (SB_{0.6msy}: 900 tons) as a limit reference point (SB_{limit}), and SSB required for 10% MSY (SB_{0.1msy}: 100 tons) as a fishing ban level (SB_{ban}) (Yamashita et al. 2021, Supplementary Table 6-2). The parameters used for these estimates are shown in Supplementary Table 3-1.

The proposed target reference points and fishing pressure (F) required for MSY are shown in the Kobe plot in Supplementary Fig. 3-1. SSB in 2021 (SB₂₀₂₁: 28,000 tons) obtained from cohort analysis is higher than the proposed target reference points, the proposed limit reference point and proposed fishing ban level. Fishing pressure of this stock since 2017 was judged to be lower than the fishing pressure required for MSY (Supplementary Table 6-3).

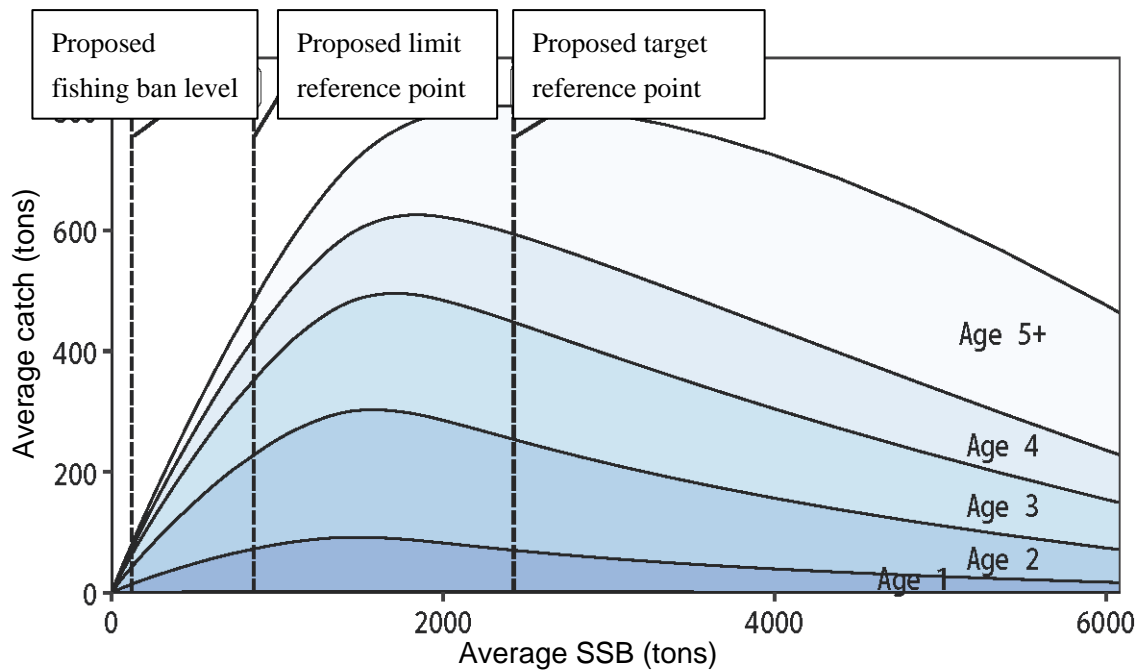
The relationship of average SSB and average catch in weight at age at equilibrium is shown in Supplementary Fig. 3-2. While the majority of the fish caught were age 1 to age 3 fish, when SSB was below the SB_{limit}, the proportion of older fish tended to increase as the SSB increased, suggesting that the catch would be dominated by fish age 3 or older at the point the SB_{msy} is achieved.

References

Yamashita, Y., Yamada, T., Manabe, A., Kanaya, S., Sakaji, H. (2021) Materials for the Research Institute Meeting on Reference Points of Seto Inland Sea stock of Bastard halibut in Fiscal Year 2021. Japan Fisheries Research and Education Agency, 1-40. FRA-SA2021-BRP04-001
http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20210928/doc_hirame_setonaikai_RIM.pdf (last accessed 13 July 2022)



Supplementary Fig. 3-1. Relationship of proposed reference points and SSB/fishing pressure (Kobe plot)



Supplementary Fig. 3-2. Relationship of average SSB and average catch in weight at age at equilibrium (catch in weight curve)

Supplementary Table 3-1 Parameters used to estimate levels required for maximum sustainable yield (MSY)

	Selectivity	Fmsy	Current fishing pressure (F2020)	Average weight (g)	Natural mortality coefficient	Maturity ratio
Age 0	0.034	0.014	0.010	107	0.078	0.000
Age 1	0.467	0.187	0.143	349	0.313	0.042
Age 2	0.922	0.369	0.283	848	0.313	0.750
Age 3	1.000	0.400	0.307	1,660	0.313	0.818
Age 4	0.949	0.380	0.291	2,651	0.313	1.000
Age 5+	0.949	0.380	0.291	3,853	0.313	1.000

Appendix 4. Future Projections Based on Proposed HCRs

(1) Setting Future Projections

Future projection calculations were performed for the 2022 to 2052 using a progression method for cohort analysis applied to estimates for stock abundance in 2021 (Appendix 5). Recruitment in future projections was predicted based on values for SSB in each year using the stock-recruitment relationship model. Calculations were replicated 10,000 times assuming errors which follow log-normal distribution to account for uncertainty in recruitment. Since the release of hatchery-reared fish is ongoing in this stock, projections were also made under the assumption that current release would continue, and projections were also made under conditions where the average survival to recruitment of released fish for 2017 to 2019 multiplied by the average number of released fish was added to the annual recruitment as hatchery-reared recruits.

Catch in weight in the 2022 was assumed based on forecasted stock abundance and current fishing mortality (F2022). The current fishing mortality is the F value that give the %SPR corresponding to fishing pressure in 2021 in this assessment, under the same selectivity and biological parameters (average body weight, etc.) as the calculations for proposed reference points. Fishing mortality in 2023 and onwards was set as the fishing mortality established in the following proposed HCRs, which are based on SSB projections for each year.

(2) Proposed Harvest Control Rules

Proposed HCRs are guidelines which sets fishing mortality (F) and other factors that correspond to SSB, in consideration of the probability of success for maintenance and/or recovery of SSB to proposed target reference points. The Harvest Control Rules and Basic Guidelines for ABC Calculation describe linear reduction of fishing mortality down to the proposed fishing ban level when SSB falls below the proposed limit reference point, and an upper limit for fishing mortality equal to F_{msy} multiplied by adjustment coefficient β when SSB is above the limit reference point. Supplementary Fig. 4-1 shows the HCRs from the Research Institute Meeting for this stock. This figure presents an example that adjustment coefficient β set to 0.8. The Research Institution Meeting proposals state that, "Although the risk of SSB falling below the limit reference point is low, β should be kept below the standard value of 0.8 because this stock has been subject to stock assessment for a short period of time and there are concerns about uncertainty in the stock-recruitment relationship and other aspects of the stock".

(3) Projected Values for 2023

The average catch in weight in 2023 calculated based on HCRs with recruitment only by stock-recruitment relationship was 958 tons when β is 0.8 and 1,156 tons when β is 1.0 (Supplementary Table 6-4a, 6-6). When current stock enhancement of hatchery-reared fish was assumed, the average catch in weight for 2023 was 966 tons when β is 0.8 and 1,166 tons when β is 1.0 (Supplementary Table 6-4b, 6-6). Projected SSB in 2023 is projected to be an average of 3,700 tons, which exceeds target reference points in all replicated calculations under both recruitment assumptions. Since the spawning biomass is above the proposed limit reference point, fishing mortality in 2023 was

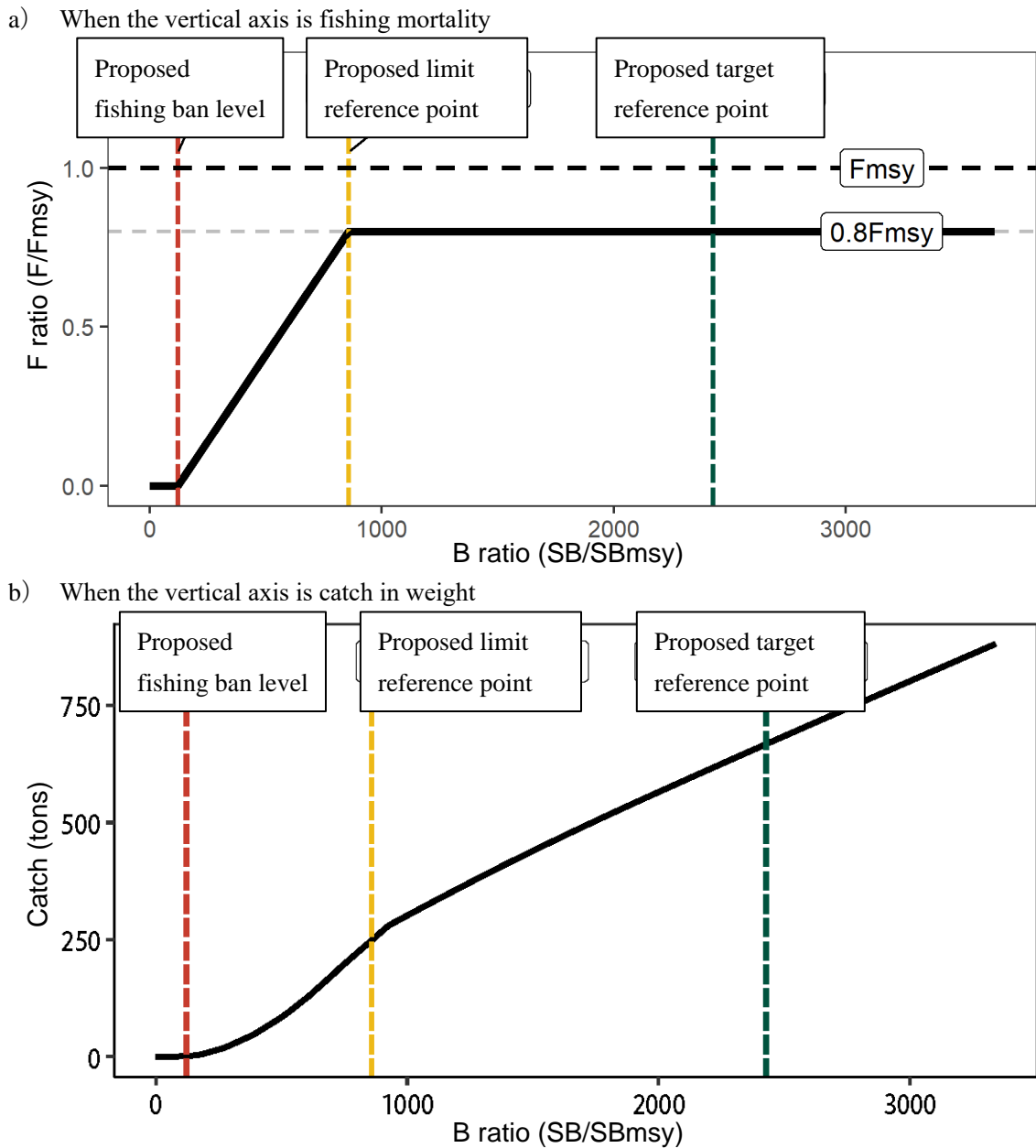
determined as $\beta \times F_{msy}$.

(4) Projections for 2024 and Onwards

Results of future projections, including 2024 and onwards, are shown in Supplementary Figure 4-2 and Supplementary Tables 4-1 to 4-4.

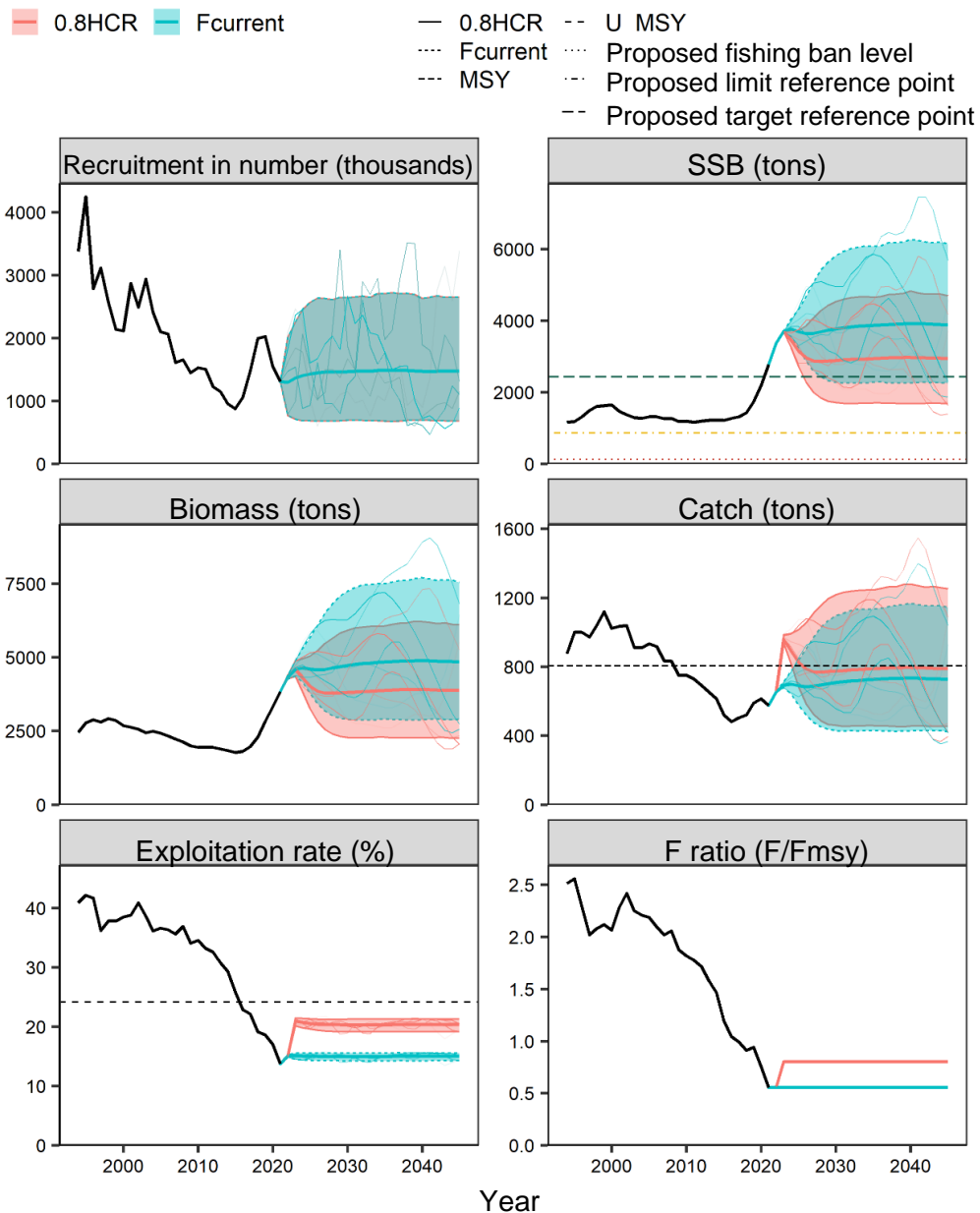
If management based on these proposed HCRs is continued for 10 years, and only recruitment by stock-recruitment relationship is assumed as future recruitment (Supplementary Fig. 4-2, Supplementary Tables 4-1a, 4-2a, 4-3a, and 4-4a), then the projected SSB in 2033 will be 2,900 tons when β is set at 0.8 (90% prediction interval: 1,700 to 4,700 tons), and 2,400 tons when β is set to 1.0 (90% prediction interval: 1,400 to 3,800 tons) (Supplementary Table 6-5a). If β is 0.9 or lower, then there is a 50% or higher probability that the projected SSB will exceed the proposed target reference point. The probability of exceeding the proposed limit reference point exceeds 50% for any β . If the current fishing mortality (F2022) is continued, then projected values for SSB in 2033 will be 3,800 tons (90% prediction interval of 2,300 to 6,100 tons), with a 92% probability that the SSB will exceed the proposed target reference point, and a 100% probability that it will exceed the proposed limit reference point.

Similarly, when current stock enhancement of hatchery-reared fish was assumed (Supplementary Fig. 4-3, Supplementary Tables 4-1b, 4-2b, 4-3b, 4-4b), then the projected SSB in 2033 will be 3,300 tons when β is 0.8 (90% prediction interval: 2,100 to 5,100 tons), and 2,700 tons when β is 1.0 (90% prediction interval: 1,700 to 4,200 tons) (Supplementary Table 6-5b). The probability that the projected SSB will exceed the proposed target reference points and the proposed limit reference point exceeds 50% for both β values. If the current fishing mortality (F2022) is continued, then projected values for SSB in 2033 will be 4,400 tons (90% prediction interval of 2,800 to 6,600 tons), with a 99% probability that SSB will exceed the proposed target reference point, and a 100% probability that it will exceed the proposed limit reference point.



Supplementary Fig. 4-1. The proposed HCRs

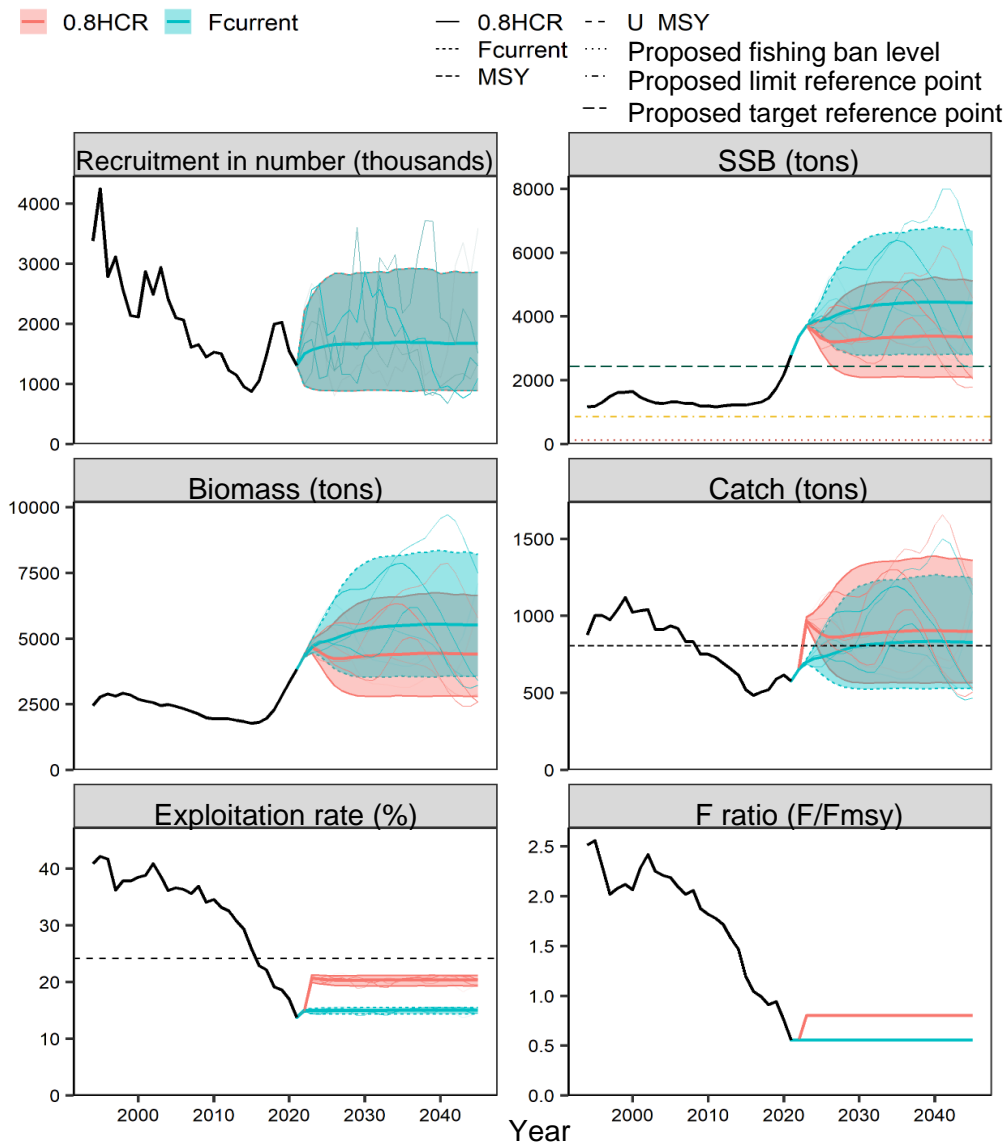
The proposed target reference point (SB_{target}) is the SB_{msy} values calculated based on a hockey-stick stock-recruitment model. Standard values are used for the proposed limit reference point (SB_{limit}) and the proposed fish ban level (SB_{ban}), respectively. An adjustment coefficient of $\beta = 0.8$, the standard value, was used. The black dashed line represents F_{msy}, the gray dashed line represents 0.8 F_{msy}, the thick black line represents HCR, the red dashed line represents the proposed fish ban level, the yellow dashed line represents the proposed limit reference point, and the green dashed line represents the proposed target reference point. Graph (a) is the scenario when the vertical axis shows fishing mortality, and graph (b) is the scenario when the vertical axis shows catch in weight. In (b), while catch in weight varies slightly depending on the age composition in the year of catch, the catch in weight for the average age composition at equilibrium is shown here.



(Shaded areas: 5 to 95% prediction interval, thick solid lines: average value, thin solid lines: simulation results)

Supplementary Fig. 4-2. Future projections based on proposed HCRs (red line), and future projections if the current fishing pressure is continued (green line).

The solid line indicates average values, the shaded area indicates the prediction interval which contains 90% of simulation results, and the thin lines indicate 3 future projections. In the SSB graph, the green dashed line is the proposed target reference point, the yellow dotted line is the proposed limit reference point, and the red dotted line is the proposed fishing ban level. In the exploitation rate graph, the dashed line indicates Umsy. In the catch graph, the dashed line indicates MSY. The 2022 catch is based on predicted biomass and current fishing mortality (F2022), while catches in 2023 onward follow the proposed HCRs (Supplementary Fig. 4-1). An adjustment coefficient of $\beta = 0.8$ was used.



(Shaded areas: 5 to 95% prediction interval, thick solid lines: average value, thin solid lines: simulation results)

Supplementary Fig. 4-3. The future projections using proposed HCRs (red) and the current fishing mortality (green), with assumption of current stock enhancement of hatchery-reared fish.

The thick solid lines are the average values, while the shaded areas are the 90% prediction interval, which contain 90% of the simulation results, and the thin lines are examples of three future projections. In the SSB graph, the green dashed line is the proposed target reference point, the yellow dotted line is the proposed limit reference point, and the red dotted line is the proposed fishing ban level. In the exploitation rate graph, the dashed line indicates U_{msy} . In the catch graph, the dashed line indicates MSY. The 2022 catch is based on predicted biomass and current fishing mortality (F_{2022}), while catches in 2023 onward follow the proposed HCRs (Supplementary Fig. 4-1). An adjustment coefficient of $\beta = 0.8$ was used. Recruitment of hatchery-reared fish in current population is the average value of released fish from 2017 to 2019 multiplied by survival to recruitment of released fish.

Supplementary Table 4-1. Probability that future SSB will exceed proposed target reference points

a) When assuming recruitment only from stock-recruitment relationships (%)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	100	100	100	100	91	53	42	40	40	40	41	42	42	43	43
0.9	100	100	100	100	99	72	58	54	53	53	54	54	54	55	55
0.8	100	100	100	100	100	88	74	68	67	67	67	67	67	68	68
0.7	100	100	100	100	100	97	87	82	80	79	79	79	79	80	79
0.6	100	100	100	100	100	100	96	92	89	88	88	88	89	89	88
0.5	100	100	100	100	100	100	99	97	96	95	95	95	95	95	95
0.4	100	100	100	100	100	100	100	99	99	98	98	98	98	98	98
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2022	100	100	100	100	100	100	98	95	93	92	92	92	92	92	92

b) Assuming current stock enhancement (%)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	100	100	100	100	99	74	63	60	59	60	60	60	61	61	61
0.9	100	100	100	100	100	90	79	75	73	73	73	73	74	74	74
0.8	100	100	100	100	100	98	91	87	85	85	85	85	85	85	85
0.7	100	100	100	100	100	100	98	95	94	93	93	93	93	93	93
0.6	100	100	100	100	100	100	100	99	98	98	98	98	98	98	98
0.5	100	100	100	100	100	100	100	100	100	99	99	99	99	100	99
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2022	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99

Recruitment of hatchery-reared fish in current stock enhancement is the average value of released fish from 2017 to 2019 multiplied by survival to recruitment of released fish.

Supplementary Table 4-2. Probability that future SSB will exceed proposed limit reference points.

a) When assuming recruitment only from stock-recruitment relationships (%)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2022	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

b) Assuming current stock enhancement (%)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2022	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Recruitment of hatchery-reared fish in current stock enhancement is the average value of released fish from 2017 to 2019 multiplied by survival to recruitment of released fish.

Supplementary Table 4-3. Trends in future average SSB

a) When assuming recruitment only from stock-recruitment relationships (tons)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	2,778	3,369	3,701	3,215	2,778	2,515	2,402	2,369	2,368	2,375	2,382	2,389	2,396	2,416	2,412
0.9	2,778	3,369	3,701	3,330	2,958	2,726	2,627	2,601	2,604	2,614	2,624	2,633	2,640	2,666	2,661
0.8	2,778	3,369	3,701	3,450	3,152	2,959	2,879	2,864	2,875	2,890	2,902	2,914	2,923	2,955	2,948
0.7	2,778	3,369	3,701	3,574	3,360	3,216	3,164	3,166	3,187	3,209	3,226	3,241	3,252	3,292	3,284
0.6	2,778	3,369	3,701	3,704	3,584	3,499	3,485	3,510	3,547	3,579	3,604	3,624	3,638	3,689	3,678
0.5	2,778	3,369	3,701	3,838	3,823	3,813	3,848	3,906	3,965	4,013	4,049	4,075	4,095	4,161	4,148
0.4	2,778	3,369	3,701	3,977	4,081	4,160	4,259	4,361	4,451	4,522	4,573	4,611	4,639	4,728	4,712
0.3	2,778	3,369	3,701	4,121	4,357	4,543	4,723	4,885	5,019	5,122	5,197	5,252	5,292	5,416	5,398
0.2	2,778	3,369	3,701	4,270	4,654	4,968	5,250	5,491	5,685	5,833	5,943	6,024	6,083	6,265	6,244
0.1	2,778	3,369	3,701	4,426	4,973	5,438	5,849	6,192	6,467	6,681	6,841	6,961	7,049	7,327	7,304
0	2,778	3,369	3,701	4,587	5,316	5,959	6,528	7,005	7,391	7,694	7,928	8,106	8,240	8,680	8,661
F2022	2,778	3,369	3,701	3,766	3,694	3,642	3,650	3,689	3,735	3,774	3,803	3,825	3,842	3,899	3,888

b) Assuming current stock enhancement (tons)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	2,778	3,369	3,704	3,289	2,930	2,741	2,681	2,675	2,687	2,701	2,712	2,721	2,729	2,752	2,748
0.9	2,778	3,369	3,704	3,406	3,116	2,965	2,927	2,933	2,953	2,972	2,986	2,997	3,006	3,034	3,029
0.8	2,778	3,369	3,704	3,527	3,316	3,213	3,203	3,226	3,257	3,283	3,302	3,316	3,327	3,362	3,355
0.7	2,778	3,369	3,704	3,653	3,531	3,485	3,514	3,561	3,607	3,643	3,669	3,687	3,701	3,744	3,736
0.6	2,778	3,369	3,704	3,784	3,761	3,786	3,864	3,943	4,010	4,061	4,096	4,122	4,140	4,196	4,185
0.5	2,778	3,369	3,704	3,919	4,008	4,117	4,258	4,380	4,477	4,549	4,598	4,634	4,658	4,732	4,720
0.4	2,778	3,369	3,704	4,060	4,272	4,484	4,703	4,882	5,020	5,120	5,191	5,241	5,276	5,377	5,361
0.3	2,778	3,369	3,704	4,206	4,557	4,888	5,207	5,459	5,652	5,793	5,894	5,965	6,016	6,160	6,142
0.2	2,778	3,369	3,704	4,357	4,862	5,336	5,777	6,125	6,391	6,590	6,733	6,837	6,911	7,125	7,104
0.1	2,778	3,369	3,704	4,514	5,190	5,831	6,423	6,894	7,259	7,536	7,741	7,892	8,003	8,332	8,311
0	2,778	3,369	3,704	4,677	5,542	6,379	7,156	7,784	8,281	8,666	8,959	9,181	9,347	9,870	9,854
F2022	2,778	3,369	3,704	3,847	3,874	3,937	4,042	4,140	4,220	4,280	4,321	4,351	4,372	4,435	4,424

Recruitment of hatchery-reared fish in current stock enhancement is the average value of released fish from 2017 to 2019 multiplied by survival to recruitment of released fish.

Supplementary Table 4-4. Trends in future average catch in weight

a) When assuming recruitment only from stock-recruitment relationships (tons)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	576	653	1,156	1,007	889	822	794	787	787	790	792	794	796	801	801
0.9	576	653	1,059	953	861	808	786	781	782	785	788	790	793	799	798
0.8	576	653	958	891	825	785	770	768	771	775	778	781	783	790	789
0.7	576	653	853	820	779	753	745	747	752	756	760	763	766	774	772
0.6	576	653	744	740	721	709	708	714	721	727	732	735	738	747	745
0.5	576	653	632	649	649	650	657	667	676	683	689	693	696	706	704
0.4	576	653	514	546	561	573	586	600	611	620	626	631	635	645	643
0.3	576	653	393	432	455	474	492	508	521	530	537	542	546	558	556
0.2	576	653	267	303	329	350	368	384	396	406	413	418	422	433	432
0.1	576	653	136	160	178	194	207	218	227	234	239	243	246	255	254
0	576	653	0	0	0	0	0	0	0	0	0	0	0	0	0
F2022	576	653	692	698	689	683	686	694	702	709	714	718	721	730	728

b) Assuming current stock enhancement (tons)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2043	2053
1.0	576	653	1,166	1,042	950	903	890	890	894	898	902	905	907	913	912
0.9	576	653	1,068	985	920	886	879	882	888	893	897	900	903	909	908
0.8	576	653	966	921	880	860	860	867	875	881	885	889	892	899	898
0.7	576	653	860	847	829	823	831	842	852	859	865	869	872	880	879
0.6	576	653	750	763	766	773	789	804	816	825	832	837	840	850	848
0.5	576	653	637	669	688	707	730	749	764	775	783	788	792	803	801
0.4	576	653	519	563	595	622	650	673	690	702	711	717	722	734	732
0.3	576	653	396	445	482	514	545	569	587	600	610	616	621	634	633
0.2	576	653	269	312	347	378	407	429	446	459	468	474	479	492	491
0.1	576	653	137	164	188	209	228	244	256	264	271	276	280	290	289
0	576	653	0	0	0	0	0	0	0	0	0	0	0	0	0
F2022	576	653	698	721	731	745	764	781	794	804	811	816	820	830	828

Recruitment of hatchery-reared fish in current stock enhancement is the average value of released fish from 2017 to 2019 multiplied by survival to recruitment of released fish.

Appendix 5. Future Projection Methods

Future projections were performed using the stock-recruitment relationship used to estimate the F value that would achieve maximum sustainable yield (F_{msy}) at the Research Institute Meeting held in September 2021 (Yamashita et al. 2021) as well as the various settings shown in Supplementary Table 5-1 (natural mortality, maturity rate, average weight by age, and current fishing mortality) according to the harvest control rules for Stock Group 1 in the Basic Guidelines for Harvest Control Rules and ABC Calculation at FY 2022 (FRA-SA2022-ABCWG02-01). The statistical software R (version 4.0.2) and the calculation package “frasyr” (commit no. f0e0c11) were used to calculate projections for stock abundance and catch in weight based on the Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations (FRA-SA2022-ABCWG02-04).

This stock is a target species of stock enhancement, and hatchery-reared fish have been released continuously (Table 4-3). When taking stock enhancement into account in future projections, the projection was made by adding 200,000 fish, the product of the average number of fish released from 2017 to 2019 (2.58 million) and the average survival to recruitment of released fish (0.0786), to annual recruitment as the number of fish added from hatchery reared fish. In previous stock assessments, the average of the most recent three years was used for the assumption of stock enhancement in future projections (Yamada and Honda 2020), but in this year’s stock assessment, as there is likely to be a high degree of uncertainty regarding the contribution rate at 2020, this value was excluded and the average value of the previous three years (2017 to 2019) was used.

The stock population of fish age 1 to 4 in future projections was obtained using the following equation.

$$N_{a,y} = N_{a-1,y-1} \exp(-M_{a-1} - F_{a-1,y-1}) \quad (a = 1, \dots, 4) \quad (18)$$

The stock population of the plus group of fish age 5 and over was obtained using the following equation.

$$N_{5+,y} = N_{4,y-1} \exp(-M_{4,y-1} - F_{4,y-1}) + N_{5+,y-1} \exp(-M_{5+,y-1} - M_{5+,y-1}) \quad (19)$$

Fishing mortality (F) in future projections was determined using the following equation based on the HCRs for Stock Group 1.

$$F_{a,y} = \begin{cases} 0 & \text{if } SB_t < SB_{ban} \\ \beta \gamma(SB_t) F_{msy} & \text{if } SB_{ban} \leq SB_t < SB_{limit} \\ \beta F_{msy} & \text{if } SB_t \geq SB_{limit} \end{cases} \quad (20)$$

$$\gamma(SB_y) = \frac{SB_y - SB_{ban}}{SB_{limit} - SB_{ban}} \quad (21)$$

In these equations, S_{By} is the SBB in year y , while F_{msy} and $S_{Btarget}$, S_{Blimit} , and S_{Bban} are the SSB reference values shown as proposed in Supplementary Table 6-2.

The catch in number at age was also obtained using the following equation.

$$C_{a,y} = N_{a,y} \left(1 - \exp(-F_{a,y}) \right) \exp\left(-\frac{M_a}{2}\right) \quad (22)$$

The biomass and catch in weight in future projections were obtained by multiplying the stock population or catch in number obtained here by the average weight in Supplementary Table 5-1, and SSB was calculated by multiplying this biomass by the maturity ratio.

References

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http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20210928/doc_hirame_setonaikai_RIM.pdf (last accessed 13 July 2022)

Supplementary Table 5-1. Set values used to calculate future projections

	Selectivity (Note 1)	Fmsy (Note 2)	F2022 (Note 3)	Average weight (g)	Natural mortality coefficient	Maturity ratio
Age 0	0.034	0.014	0.008	107	0.078	0.000
Age 1	0.467	0.187	0.103	349	0.313	0.042
Age 2	0.922	0.369	0.204	848	0.313	0.750
Age 3	1.000	0.400	0.221	1,660	0.313	0.818
Age 4	0.949	0.380	0.210	2,651	0.313	1.000
Age 5+	0.949	0.380	0.210	3,853	0.313	1.000

Note 1: Selectivity was used to estimate the level required for MSY at the FY 2021 Research Institute Meeting (i.e., selectivity of $F_{current}$ in the FY2021 stock assessment).

Note 2: Fmsy was estimated at the FY 2021 Research Institute Meeting (i.e., $F_{msy}/F_{current}$ multiplied by $F_{current}$ in the FY2021 stock assessment).

Note 3: Under the selectivity above, an F value that gives the same fishing pressure as the F value by age in 2021 estimated in this stock assessment was calculated by conversion to %SPR. This F value was used for the assumed catch in weight for 2022.

Appendix 6 Summary of Various Parameters and Assessment Results

Supplementary Table 6-1. Parameters for stock-recruitment relationship model

Stock-recruitment relationship model	Optimization method	Autocorrelation	a	b	S.D.	ρ
Hockey-stick model	Least squares method	Yes	1.28	1,154	0.294	0.703

In this table, a and b are the estimated parameters of the stock-recruitment relationship model, S.D. is the standard deviation of recruitment in number, and ρ is the autocorrelation coefficient.

Supplementary Table 6-2. Proposed reference points and MSY

Item	Value	Description
SBtarget (proposed)	2,427 tons	A proposed target reference point. SSB required for MSY (SB _{msy}).
SBlimit (proposed)	857 tons	A proposed limit reference point. SSB required for catch of 60% of MSY (SB _{0.6msy}).
SBban (proposed)	121 tons	Proposed fishing ban level. SSB required for catch of 10% of MSY (SB _{0.1msy}).
F _{msy}	Fishing pressure required for MSY (fishing mortality F) (Age 0, Age 1, Age 2, Age 3, Age 4, Age 5 and older) = (0.01, 0.19, 0.37, 0.40, 0.38, 0.38)	
%SPR (F _{msy})	28%	%SPR corresponding to F _{msy}
MSY	806 tons	Maximum Sustainable Yield

Supplementary Table 6-3. SSB and fishing pressure in most recent year

Item	Value	Description
SB2021	2,778 tons	SSB in 2021
F2021	Fishing pressure in 2021 (fishing mortality F) (Age 0, Age 1, Age 2, Age 3, Age 4, Age 5 and older) = (0.01, 0.09, 0.21, 0.22, 0.21, 0.21)	
U2021	15.1%	Exploitation rate in 2021
%SPR (F2021)	44.9%	%SPR in 2021
Compared against proposed reference points		
SB2021 / SB _{msy} (SB _{target})	1.14	B ratio required for MSY (proposed target reference point) to SSB in 2021 fishing season
F2021 / F _{msy}	0.55	F ratio required for MSY to fishing pressure in 2021*
Level of SSB	Over the level required for MSY	
Level of fishing pressure	Under the level required for MSY	
Changes in SSB	Increase	

*Ratio calculated based on F converted to %SPR, which gives the fishing pressure of F_{msy} under the selectivity of 2021.

Supplementary Table 6-4. Projected catch in weight and projected SSB

a) When assuming recruitment only from stock-recruitment relationships

SSB in 2023 fishing season (average projected value): tons			
Item	Catch (tons) in 2023	Ratio to current fishing pressure (F/F2022)	Exploitation rate in 2023 (%)
$\beta = 1.0$	1,156	1.81	25.2
$\beta = 0.9$	1,059	1.63	23.1
$\beta = 0.8$	958	1.45	20.9
$\beta = 0.7$	853	1.27	18.6
$\beta = 0.6$	744	1.08	16.2
$\beta = 0.5$	632	0.90	13.8
$\beta = 0.4$	514	0.72	11.2
$\beta = 0.3$	393	0.54	8.6
$\beta = 0.2$	267	0.36	5.8
$\beta = 0.1$	136	0.18	3.0
$\beta = 0$	0	0.00	0.0
F2022	692	1.00	15.1

b) Assuming current stock enhancement

SSB in 2023 fishing season (average projected value): tons			
Item	Catch (tons) in 2023	Ratio to current fishing pressure (F/F2022)	Exploitation rate in 2023 (%)
$\beta = 1.0$	1,166	1.81	25.0
$\beta = 0.9$	1,068	1.63	22.9
$\beta = 0.8$	966	1.45	20.7
$\beta = 0.7$	860	1.27	18.4
$\beta = 0.6$	750	1.08	16.1
$\beta = 0.5$	637	0.90	13.6
$\beta = 0.4$	519	0.72	11.1
$\beta = 0.3$	396	0.54	8.5
$\beta = 0.2$	269	0.36	5.8
$\beta = 0.1$	137	0.18	2.9
$\beta = 0$	0	0.00	0.0
F2022	698	1.00	14.9

Recruitment of hatchery-reared fish in current stock enhancement is the average value of released fish from 2017 to 2019 multiplied by survival to recruitment of released fish.

Supplementary Table 6-5. Results of future projections using various β

a) When assuming recruitment only from stock-recruitment relationships

Uncertainty under consideration: Recruitment volume					
β	SSB in 2033 (tons)	90% prediction interval (tons)	Probability (%) that SSB will exceed the following proposed reference points in 2033		
			SBtarget (proposed)	SBlimit (proposed)	SBban (proposed)
$\beta = 1.0$	2,396	1,362 – 3,849	42	100	100
$\beta = 0.9$	2,640	1,513 – 4,231	54	100	100
$\beta = 0.8$	2,923	1,691 – 4,662	67	100	100
$\beta = 0.7$	3,252	1,894 – 5,165	79	100	100
$\beta = 0.6$	3,638	2,137 – 5,742	89	100	100
$\beta = 0.5$	4,095	2,425 – 6,440	95	100	100
$\beta = 0.4$	4,639	2,767 – 7,276	98	100	100
$\beta = 0.3$	5,292	3,188 – 8,248	100	100	100
$\beta = 0.2$	6,083	3,694 – 9,421	100	100	100
$\beta = 0.1$	7,049	4,319 – 10,836	100	100	100
$\beta = 0$	8,240	5,104 – 11,550	100	100	100
F2022	3,842	2,263 – 6,058	92	100	100

b) Assuming current stock enhancement

Uncertainty under consideration: Recruitment volume					
β	SSB in 2033 (tons)	90% prediction interval (tons)	Probability (%) that SSB will exceed the following proposed reference points in 2033		
			SBtarget (proposed)	SBlimit (proposed)	SBban (proposed)
$\beta = 1.0$	2,729	1,698 – 4,181	61	100	100
$\beta = 0.9$	3,006	1,881 – 4,596	74	100	100
$\beta = 0.8$	3,327	2,095 – 5,066	85	100	100
$\beta = 0.7$	3,701	2,344 – 5,614	93	100	100
$\beta = 0.6$	4,140	2,639 – 6,244	98	100	100
$\beta = 0.5$	4,658	2,989 – 7,003	99	100	100
$\beta = 0.4$	5,276	3,404 – 7,913	100	100	100
$\beta = 0.3$	6,016	3,912 – 8,972	100	100	100
$\beta = 0.2$	6,911	4,522 – 10,249	100	100	100
$\beta = 0.1$	8,003	5,273 – 11,790	100	100	100
$\beta = 0$	9,347	6,211 – 13,657	100	100	100
F2022	4,372	2,793 – 6,588	99	100	100

Recruitment of hatchery-reared fish in current stock enhancement is the average value of released fish from 2017 to 2019 multiplied by survival to recruitment of released fish.

Supplementary Table 6-6. Summary of projected SSB, catch in weight, and probability of SSB exceeding proposed reference points for varying recruitment assumptions

Assumptions for future recruitment	β	Probability of exceeding the target in 10 years (%)	Projected average SSB (tons)		Projected average catch (tons)		
		Probability of SSB exceeding the proposed target reference points	In 5 years	In 10 years	In 0 years	In 5 years	In 10 years
			2028	2033	2023	2028	2033
Recruitment according to stock-recruitment relationship only	1	42	2,435	2,396	1,156	787	796
	0.9	54	2,671	2,640	1,059	781	793
	0.8	67	2,939	2,923	958	768	783
	0.7	79	3,244	3,252	853	747	766
	0.6	89	3,592	3,638	744	714	738
	0.5	95	3,991	4,095	632	667	696
	F2022	92	4,435	3,842	692	694	721
Stock enhancement taken into account* (2.58 million fish released, survival to recruitment 0.08)	1	61	3,208	2,729	1,166	890	907
	0.9	74	3,510	3,006	1,068	882	903
	0.8	85	3,852	3,327	966	867	892
	0.7	93	4,240	3,701	860	842	872
	0.6	98	4,682	4,140	750	804	840
	0.5	99	5,187	4,658	637	749	792
	F2022	99	7,035	4,372	698	781	820

The results of changing the adjustment coefficient β in the proposed HCRs from 0.5 to 1.0 in increments of 0.1 are compiled here.

Values for 2023, the first year (year 0) of management under the proposed HCRs, are shown here along with values after 5 years and 10 years of management (2028 and 2033).

*When we considered the stock enhancement, the recruitment from hatchery-reared fish was 200,000, which is the product of the yearly average number of released fish from 2017 to 2019 (2.58 million) multiplied by survival to recruitment of released fish (0.0786).